इंटरनेट मानक

Disclosure to Promote the Right To Information

Whereas the Parliament of India has set out to provide a practical regime of right to information for citizens to secure access to information under the control of public authorities, in order to promote transparency and accountability in the working of every public authority, and whereas the attached publication of the Bureau of Indian Standards is of particular interest to the public, particularly disadvantaged communities and those engaged in the pursuit of education and knowledge, the attached public safety standard is made available to promote the timely dissemination of this information in an accurate manner to the public.

“जानने का अधिकार, जीने का अधिकार”
Mazdoor Kisan Shakti Sangathan
“The Right to Information, The Right to Live”

“पुराने को छोड नये के तरफ”
Jawaharlal Nehru
“Step Out From the Old to the New”

IS 7788 (1975): Single-phase traction power converters [ETD 31: Power Electronics]

“ज्ञान से एक नये भारत का निर्माण”
Satyanarayan Gangaram Pitroda
“Invent a New India Using Knowledge”

Act Number 22 of 2005
The Indian Parliament
RIGHT TO INFORMATION

Made Available By
Public.Resource.Org

“ज्ञान एक ऐसा खजाना है जो कभी चुराया नहीं जा सकता है”
Bhartṛhari—Nītiśatakam
“Knowledge is such a treasure which cannot be stolen”

BLANK PAGE

BRUTUM FULMEN

IGNORANTIA
JURIS
NON EXCUSAT

PROTECTED BY COPYRIGHT

IS : 7788 - 1975

(Reaffirmed 2001)

Indian Standard

SPECIFICATION FOR SINGLE-PHASE TRACTION POWER CONVERTORS

UDC 621·314·57 : 621·333/·335

© *Copyright* 1976

INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

~~*Price Rs 20.00*~~ Gr 11

February 1976

Indian Standard

SPECIFICATION FOR SINGLE-PHASE TRACTION POWER CONVERTORS

Power Convertors Sectional Committee, ETDC 31

Chairman	*Representing*
Shri A. K. Khosla	Bharat Heavy Electricals Ltd, Bhopal
Members	
Shri M. S. Srinivasa Murthy (*Alternate* to Shri A. K. Khosla)	
Additional Chief Engineer	Directorate General of Posts & Telegraphs, Jabalpur
Director of Telegraphs (X) (*Alternate*)	
Divisional Engineer Telegraphs (Auto) (*Alternate*)	
Shri R. S. Arora	Directorate General of Supplies & Disposals (Inspection Wing), New Delhi
Shri V. S. Kripalani (*Alternate*)	
Shri P. K. Banerjee	Hindustan Steel Ltd, Ranchi
Shri S. L. Bhatia (*Alternate*)	
Dr R. L. Choudhury	Usha Rectifier Corporation (India) Ltd, Faridabad
Shri S. C. Choudhery (*Alternate*)	
Director Standards (Elec)	Railway Board (Ministry of Railways)
Deputy Director Standards (Elec 3) (*Alternate*)	
Director (Transmission)	Central Electricity Authority, New Delhi
Deputy Director (Transmission) (*Alternate*)	
Shri M. W. Dukle	E. Ruttonsha Pvt Ltd, Bombay
Shri M. S. Patwardhan (*Alternate*)	
Shri T. K. Ghose	The Calcutta Electric Supply Corporation Ltd, Calcutta
Shri P. K. Bhattacharjee (*Alternate*)	
Shri M. S. Jayasimha	Indian Telephone Industries Ltd, Bangalore
Shri S. T. Pillai (*Alternate*)	
Shri S. M. Kher	Hind Rectifiers Limited, Bombay
Shri A. B. Kalbag (*Alternate*)	

(*Continued on page* 2)

© *Copyright* 1976

INDIAN STANDARDS INSTITUTION

This publication is protected under the *Indian Copyright Act* (XIV of 1957) and reproduction in whole or in part by any means except with written permission of the publisher shall be deemed to be an infringement of copyright under the said Act.

(*Continued from page* 1)

Members	*Representing*
Lt-Col K. V. Kudva	Directorate of Standardization, Ministry of Defence (DGI)
Shri S. K. Mani (*Alternate*)	
Shri S. K. Malik	The Fertilizers Corporation of India Ltd, Nangal
Shri Guru Partap (*Alternate*)	
Shri R. Manmohan	Elvoc Private Ltd, Calcutta
Dr J. K. Choudhury (*Alternate*)	
Shri T. K. Misra	Siemens India Ltd, Bombay
Shri A. V. Chindarkar (*Alternate*)	
Shri K. N. Ramaswamy	Directorate General of Technical Development, New Delhi
Shri G. L. Keswani (*Alternate*)	
Shri Rishi Pratap	Bharat Heavy Electricals Ltd (R & D), Hyderabad
Shri D. N. Sen	Martin Burn Ltd, Calcutta
Shri R. K. Dutt (*Alternate*)	
Shri M. S. Surana	Hindustan Aluminium Corporation Ltd, Renukoot
Shri M. B. Tambakad	NGEF Ltd, Bangalore
Shri A. N. Tandon (*Alternate*)	
Shri N. Srinivasan, Director (Elec tech)	Director General, ISI (*Ex-officio Member*)

Secretary

Shri R. C. Jain
Deputy Director (Elec tech), ISI

Panel for Single Phase Traction Power Convertors, ETDC 31 : P3

Convener	
Shri S. Malaviya	Railway Board (Ministry of Railways)
Members	
Director Standards (Elec)	Railway Board (Ministry of Railways)
Shri M. W. Dukley	E. Ruttonsha Pvt Ltd, Bombay
Shri S. M. Kher	Hind Rectifiers Limited, Bombay
Shri M. S. Srinivasa Murthy	Bharat Heavy Electricals Ltd, Bhopal
Shri M. B. Tambakad	NGEF Ltd, Bangalore

Indian Standard

SPECIFICATION FOR SINGLE-PHASE TRACTION POWER CONVERTORS

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 19 September 1975, after the draft finalized by the Power Convertors Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 The single phase traction power convertors used in this country employ mercury arc convertors of ignitron or excitron types with single or multiple anode valves, and convertors using semiconductor diodes. This standard covers the convertors using semiconductor diodes which are most commonly used at present in this country.

0.3 While preparing this standard, considerable assistance has been derived from IEC Publication 411(1973) ' Single-phase traction power convertors ', issued by the International Electrotechnical Commission, and the various specifications issued by the Indian Railways for traction semiconductor convertors.

0.4 It is intended to prepare a separate specification later to cover thyristor power convertors/invertors for traction application on rolling stock.

0.5 List of principal letter symbols used in this standard is given in Appendix A.

1. SCOPE

1.1 This standard applies to convertors using semiconductor diodes intended for service on single-phase rolling stock supplied with current of frequency between 15 Hz and 60 Hz.

NOTE 1 — This standard has been drawn for convertors supplying vehicle traction circuits; it also applies in principle to convertors provided for feeding the auxiliary services of those vehicles.

NOTE 2 — The general requirements of semiconductor convertor units covered by this specification shall generally be governed by IS : 3895-1966* and IS : 4540-1968†.

---

*Monocrystalline semiconductor rectifier cells and stacks.

†Monocrystalline semiconductor rectifier assemblies and equipment.

1.1.1 Power convertors covered by this specification may be used as:

a) the power convertor feeding traction motors on 50 Hz ac locomotives and electrical multiple units; and
b) Auxiliary convertor feeding auxiliary motors or auxiliary circuits on traction vehicles.

1.2 This specification does not apply to the following:

a) Single and multiphase power convertor used for traction sub-station,
b) Single or multiphase power convertor for industrial application, and
c) Single and multiphase auxiliary convertor for general application.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply.

2.1 Terms Applicable to Cooling

2.1.1 *Natural Air Cooling* — Cooling by the natural convection of the ambient air.

2.1.2 *Cooling by Forced Ventilation* — Cooling by a forced ventilation arrangement, for example, a fan. The cooling air may be taken from the immediate proximity or from a place at a different temperature from that of the ambient air.

2.1.3 *Fluid-to-Air Cooling* — Cooling by a circulating heat transfer agent (gas or liquid) which is cooled by air. The fluid circulation and the air cooling may be natural or forced.

2.1.4 *Fluid-to-Water Cooling* — Cooling by a circulating heat transfer agent (gas or liquid) which is cooled by water from an external supply, either in a heat exchanger or in a cooling duct within the fluid. The fluid circulation may be natural or forced.

2.1.5 *Liquid Immersed Natural Cooling* — Cooling by a thermo-siphon circulating liquid heat transfer agent which is cooled by natural air circulation on the outside of the container.

2.1.6 *Liquid Immersed Forced Cooling* — Cooling by a thermo-siphon circulated liquid which is cooled by forced air cooling on the outside of the containers.

2.1.7 *Ambient Temperature for Semiconductor Stacks Rated for Natural Air Cooling* — The temperature of the air directly below the rectifier stack when it is in service under rated service conditions.

2.1.8 *Cooling Air Temperature for Semiconductor Stacks Rated for Cooling by Forced Ventilation* — The temperature of the cooling air immediately before its entry into the stacks.

2.1.9 *Cooling Medium Temperature* — The temperature of the incoming cooling medium.

2.2 Electrical Characteristics of Diode

2.2.1 *Forward Direction* — The direction of the flow of continuous (direct) current in which a semiconductor diode has the lower resistance.

2.2.2 *Reverse Direction* — The direction of the flow of continuous (direct) current in which a semiconductor diode has the higher resistance.

2.2.3 *Forward Voltage, U_F* — The voltage across the terminals which results from the flow of current in the forward direction.

2.2.4 *Threshold Voltage, U_{TO}* — The value of the voltage obtained at the intersection of the voltage axis and the straight line which represents approximately the forward voltage-current characteristic.

2.2.5 *Forward Slope Resistance* — The value of the resistance calculated from the slope of the straight line used when determining the threshold voltage.

2.2.6 *Forward Current, I_F* — The current which flows in the forward direction of a rectifier diode.

2.2.6.1 *Mean forward current, I_{FAV}* — The value of the forward current averaged over the full cycle.

2.2.6.2 *Overload forward current, $I_{F(OV)}$* — A forward current the continuous application of which would cause the maximum rated virtual junction temperature to be exceeded but which is limited in time such that this temperature is not exceeded.

2.2.6.3 *Repetitive peak forward current, I_{FRM}* — The peak value of the forward current including all repetitive transient currents.

2.2.6.4 *Surge forward current, I_{FSM}* — A current the application of which causes the maximum rated virtual junction temperature to be exceeded, but which is assumed to occur only rarely with a limited number of occurences during the service life of the device and to be a consequence of unusual circuit conditions (for example, fault conditions).

2.2.6.5 *Surge forward current (with reverse voltage)* — It is the maximum allowable instantaneous value of a single current pulse in the shape of a 50 Hz half sine-wave followed by the specified reverse voltage applied during the other half non-conducting period.

NOTE — Due to the surge current the maximum rated virtual junction temperature will be exceeded (in case of surge following nominal load current). But this increased temperature should not affect the diode in any way and it will be able to withstand the applied reverse voltage just after the surge.

2.2.6.6 *Surge forward limit current with no reverse voltage* — It is the maximum allowable instantaneous value of a single current pulse in the shape of a 50 Hz half sine-wave, followed by *no* reverse voltage applied during the other half non-conducting period.

NOTE — It should never be envisaged as part of the normal operation. After the surge there shall be an interval of atleast 1 minute till the next surge comes. After the test, there shall be no detectable changes in diode characteristics.

2.2.7 *Forward Power Loss, P_F* — The power losses resulting from the flow of forward current.

NOTE — The forward power loss P_F is the mean value of the product of the instantaneous forward voltage U_F and the instantaneous forward current I_F averaged over a full cycle with the duration T. It is expressed by the following formula:

$$P_F = \frac{1}{T}\int_O^T U_F I_F \, dT$$

2.2.8 *Reverse Voltage*

2.2.8.1 *Crest working reverse voltage, U_{RWM}* — The highest instantaneous value of the reverse voltage which may be applied over a semiconductor rectifier diode excluding all repetitive and non-repetitive transient voltages.

2.2.8.2 *Repetitive peak reverse voltage, U_{RRM}* — The highest instantaneous value of the reverse voltage of a semiconductor rectifier diode including all repetitive transient voltages, but excluding all non-repetitive transient voltages.

NOTE — The repetitive voltage value applied is usually a function of the circuit and increases the power dissipation of the device.

2.2.8.3 *Non-repetitive peak reverse voltages, U_{RSM}* — The highest instantaneous value of any non-repetitive transient reverse voltage which may be applied over a semiconductor rectifier diode.

NOTE — The non-repetitive transient voltage value applied is usually due to an external cause and it is assumed that its effect has completely disappeared before the next transient arrives.

2.2.8.4 *Recovery charge* — The total charge residual in the device when switching from a specified forward current condition to a specified reverse voltage blocking condition. The charge is defined by $\int I_{dt}$ corresponding to the reverse recovery current.

2.2.9 *Reverse Current, I_R* — The leakage current flowing in the reverse direction of a diode.

2.2.10 *Thermal Resistance, R_{th}* — The quotient of the temperature difference between two specified points or regions and the heat flow between these two points or regions under conditions of thermal equilibrium.

NOTE — For most cases, the heat flow may be assumed to be equal to the power dissipation.

2.2.11 *Transient Thermal Impedance,* $Z_{(th)t}$ — Quotient of:

a) the variation of the temperature difference, reached at the end of a time interval between the virtual junction temperature and the temperature at a specified external reference point; and

b) the step function change of power dissipation at the beginning of the same time interval causing the change of temperature.

Immediately before the beginning of this time interval the distribution of temperature shall have been constant with time.

NOTE — Transient thermal impedance is given as a function of the time interval.

2.3 Electrical Terms Relating to Convertor Assembly

2.3.1 *Convertor Connections*

2.3.1.1 *Single way connection* — A method of connection of a convertor such that each of the phase terminals of the ac circuit is connected only to anodes or to cathodes.

2.3.1.2 *Double way connection* — A method of connection of a convertor such that each of the phase terminals of the ac circuit is connected both to anodes and to cathodes.

2.3.2 *Total Power Factor,* λ — It is the ratio of active power to apparent power.

2.3.3 *Power Factor of Fundamental Wave or Displacement Factor, Cos* θ — It is the ratio of active power of the fundamental wave to the apparent power of the fundamental wave.

2.3.4 *Distortion Factor* — It is the ratio of total power factor to power factor of fundamental wave.

2.3.5 *DC Ripple Factor* — The dc ripple factor, expressed in percentage is given conventionally by the formula:

$$\frac{I_{max} - I_{min}}{I_{max} + I_{min}} \times 100$$

In which I_{max} and I_{min} represent respectively maximum and minimum values of the current wave.

2.3.6 *DC Form Factor* — The ratio of the rms current on the dc side to its mean value.

2.3.7 *Power Efficiency* — The power efficiency is the ratio of the total power on the dc side to the total power on the ac side.

NOTE — The power efficiency can be obtained either by measurement with wattmeters of the powers on ac and dc sides (direct measurement method) or by calculation taking into account the losses in the convertor (summation of losses method).

2.3.8 *Conversion Efficiency* — In the case of single phase convertors supplying loads, such as traction motors, it is generally preferred to utilize the conversion efficiency which is defined as the ratio of the product of the mean values of the voltage and the current on the dc side to the total power on the ac side.

NOTE — The conversion efficiency may be obtained either by measurements with a wattmeter of the power on the ac side and with a voltmeter and an ammeter of the power of the dc component of the rectified current (direct measurement method) or by calculation taking into account the losses in the convertor as well as the power of the ac components of the voltage and current waves in the dc circuit.

2.4 Terms Relating to Convertor Transformer

2.4.1 *Line Winding* — The windings which are connected to the ac supply.

2.4.2 *Cell Winding* — The windings which are connected to the rectifier cells of a rectifier assembly.

2.4.3 *Principal Tapping* — The tapping which corresponds (exactly or most nearly) to the rated voltage of the transformer as specified by purchaser.

2.4.4 *Percentage Resistance* — Resistive voltage drop of the transformer at a reference temperature of 75°C expressed as a percentage of the rated primary voltage.

2.4.5 *Percentage Impedance Voltage* — The voltage expressed as a percentage of the rated primary voltage, and corrected to a reference temperature of 75°C, required to be applied to the primary when the secondary winding is/windings are short-circuited to cause the rated primary current to flow into the terminals of the primary winding, or vice versa; in the latter case it is expressed as a percentage of the rated secondary voltage for the specified kVA. The associated tapping should be the principal tapping as defined in **2.4.3** unless otherwise stated. The impedance voltage drop may be measured at a current less than the rated current and the value corrected in proportion to the current.

2.4.6 *Magnetising Current* — The current drawn by the line winding at the rated line voltage with the cell and auxiliary windings at no load.

2.5 Terms Relating to Smoothing Reactor

2.5.1 *Resistance* — Resistance of reactor at a reference temperature of 75°C.

2.5.2 *Reactance at Rated Current* — Reactance when smoothing reactor is carrying the rated continuous direct current at a reference temperature of 75°C, expressed with reference to 50 Hz.

2.5.3 *Saturated Reactance* — Reactance when smoothing reactance is saturated while carrying high direct current, expressed with reference to 50 Hz.

2.6 Terms Relating to Voltage Regulation

2.6.1 *Conventional No-Load Direct Voltage* U_{do} — The mean value of the direct voltage which would be obtained by extrapolating the direct voltage/current characteristic for continuous direct current back to zero current.

2.6.2 *Ideal No-Load Direct Voltage*, U_{dio} — The ideal no-load mean direct voltage of a convertor, which assumes no reduction by phase control, no voltage drop in the assemblies and no voltage rise at small loads, is obtained from the voltage between two commutating phases U_{vo}, the commutating number q and the number of series-connected commutating groups s between terminals on dc side, by the formula:

$$U_{dio} = U_{vo} \times \frac{\sqrt{2}}{2} \times \frac{q \times s}{\pi}$$

This formula is not valid for voltage multiplying circuits.

U_{dio} is equal to the sum of U_{do} and no-load voltage drop in the assembly.

In the single-phase case, the formula becomes:

$U_{dio} = \frac{\sqrt{2}}{\pi} \times U_{vo} = 0{\cdot}45\ U_{vo}$ for single-way connection.

$U_{dio} = \frac{2\sqrt{2}}{\pi} \times U_{vo} = 0{\cdot}9\ U_{vo}$ for double-way connection.

U_{vo} being the value defined in **4.3.2.2.**

When the dc voltage is obtained by the series connection of several single-phase convertors, the above formula is applicable for each individual convertor. The resulting ideal no-load dc voltage is then the sum of the ideal no-load dc voltages of all convertors.

2.6.3 *Voltage Regulation* — The difference between the direct voltage at rated direct current and the conventional no-load direct voltage (*see* Fig. 1) expressed in volts, when the voltage remains constant at the ac line side terminals of the convertor equipment.

NOTE — The nature of the dc circuit (for example capacitors, back emf load) may affect the voltage regulation significantly. Where this is so, special consideration may be required.

2.6.3.1 *Inherent voltage regulation* — The voltage regulation excluding the effect of ac system impedance and the correcting effect of voltage stabilizing means, if any.

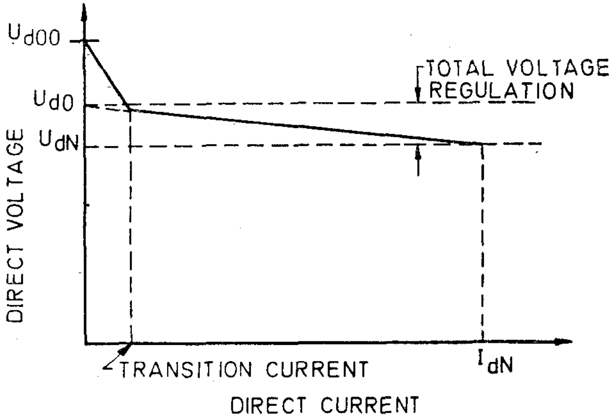


FIG. 1 DC OUTPUT VOLTAGE/CURRENT CHARACTERISTIC

2.6.3.2 *Total voltage regulation* — The voltage regulations including the effect of the ac system impedance, where specified, but excluding the correcting effect of stabilising means, if any.

2.6.4 *Corrected Voltage Regulation* (*Stabilization*) — The voltage regulation (*see* **2.6.3**) when equipment for stabilization is included in a convertor. The influence on direct voltage of factors other than load change is to be excluded. This definition only includes the static properties of the equipment.

2.7 Type Tests — The tests carried out to prove conformity with the requirements specified and agreed to between the user and the supplier according to this standard.

Some or all of these tests may be repeated from time to time on samples drawn from current production or deliveries, so as to confirm that the quality of the product meets the specified requirements.

2.8 Routine Tests — Tests carried out to verify that the properties of a product correspond to those measured during the type test.

NOTE — A routine test means that each one of several components or equipments of the same type is tested.

2.9 Investigation Tests — Tests carried out to determine the special characteristics of the equipment are sometimes in the nature of investigation tests. The tests shall be carried out as agreed to between the manufacturer and the purchaser.

3. SERVICE CONDITIONS

3.1 Normal Service Conditions — This specification applies to equipment used in the following conditions.

3.1.1 *Altitude* — In the absence of information on the height above mean sea level at which the equipment is normally to function, it is to be assumed that this height shall not exceed 1 000 metres.

3.1.2 *Temperature and Air Humidity* — In the absence of information on the ambient temperatures in which the equipment is normally to function, it is to be taken that the temperature limit shall be between − 25°C and + 55°C. For equipment mounted inside the vehicle a maximum air temperature of 60°C and a maximum relative air humidity of 100 percent may be assumed.

3.1.3 *Mechanical vibrations and Shocks* — In the absence of information concerning the degree of vibration and shocks, to which the convertor and its mounting arrangements are likely to be subjected in service, it is to be assumed:

a) that the vibration is of sine-wave form, the frequency of vibration is between 1 and 50 Hz, and that the amplitude a, expressed in mm is given as a function of f, by the equations:

$$a = \frac{25}{f} \text{ for values of } f \text{ from 1 up to 10 Hz}$$

$$a = \frac{250}{f^2} \text{ for values of } f \text{ exceeding 10 and up to 50 Hz}$$

b) that the maximum accelerations of shocks are:

horizontally (in the direction of motion of the vehicle)	3 g
transversely	2 g
vertically	1 g

g being the value of acceleration due to gravity.

3.1.4 *Other Service Conditions* — For other service conditions reference may be made to **5.2.**

3.1.5 *Installation* — With regard to its location and method of installation on the vehicle, the equipment exposed to atmosphere shall be capable of performing their functions satisfactorily in snow, rain, mist, dirt and dust to which rolling stock is normally exposed in service.

The equipment mounted inside the vehicle are also likely to be exposed to dust and minor oil fumes and the design shall take due account of this.

3.2 *Unusual Service Conditions* — Special arrangements shall be agreed to between the purchaser and the manufacturer to cover the case of service conditions of greater severity than those mentioned in **3.1**, such as:

a) altitude above 1 000 metres;

b) ambient temperature exceeding 60°C;

c) minimum temperature below — 25°C;

d) sandstorms, excessive dust, saline atmosphere (for example nearness to sea), tropical rain, frequent storms of exceptional violence;

e) special conditions like vermin-proofing, protection against large insects, termites, etc; and

f) other exceptional service conditions not included in the above.

4. RATINGS

4.1 General

4.1.1 The rated value or values of the electrical, thermal, mechanical and environmental quantities assigned to define the operating conditions under which a diode or diode stack or a convertor assembly is expected to give satisfactory service. All ratings shall also define the limiting values, maximum or minimum.

NOTE — Unlike many other electrical components, semiconductor devices may be irreparably damaged by operation in excess of the maximum rated values.

4.1.2 Where not otherwise specified, all ratings and other information covered by this standard shall apply for a practically sinusoidal alternating voltage at the ac terminals of the convertor when it is switched off.

4.1.3 The wave-form of a voltage is considered practically sinusoidal in this standard if the difference between the instantaneous value *a* and the instantaneous value *b* of the fundamental wave does not exceed 10 percent of the peak value *c* of the fundamental wave (*see* Fig. 2), that is, $(a - b) \leqslant 0{\cdot}10\ C$.

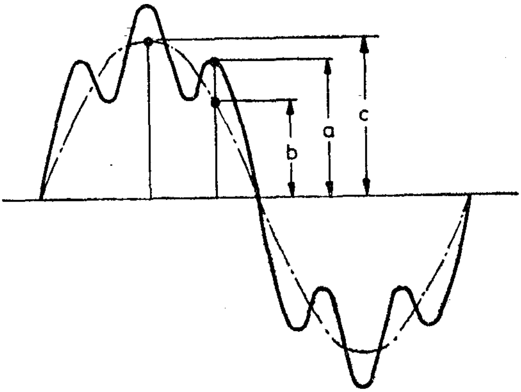


FIG. 2 WAVE-FORM FOR ALTERNATING VOLTAGE

NOTE — If the ac line voltages are not perfectly sinusoidal even though within the limits specified above, the measured value of the convertor direct voltage may deviate from the calculated value.

4.2 Ratings of Convertor Assembly

4.2.1 *Rated Continuous Direct Current,* I_{dN} — The mean value of the direct current which the convertor assembly is capable of carrying continuously.

NOTE — For traction application this is to be taken as the mean starting dc current, during normal notching operation of the traction vehicle, unless otherwise specified by the purchaser.

4.2.2 *Rated Direct Voltage,* U_{dN} — The rated mean value of the voltage between dc terminals of the convertor corresponding to the rated continuous direct current I_{dN} at the rated line voltage U_{LN} at the principal transformer tap.

4.2.3 *Rated Continuous DC Power* — The product of the rated direct voltage U_{dl} and the rated continuous direct current I_{dN}.

4.2.4 *Short Time Rating* — The convertor may also have assigned to it direct current ratings of shorter duration but of higher values to cater for temporary overloads and fault conditions. The other corresponding quantities which depend on the direct current will vary accordingly (for example, the current on the line side); but generally they will not be specified or guaranteed.

4.2.5 *Surge Current Ratings* — The surge current rating is the capacity of the convertor to withstand maximum designed fault current for the specified clearing period given by the purchaser. This should be mutually agreed to between purchaser and manufacturer.

4.2.6 *Specified Duty Cycle* — The duty cycle specified by the purchaser preferably by means of a diagram showing the variations of the direct current with the time depicting the operating duty cycle.

4.3 Ratings of Convertor Transformer

4.3.1 *Rated Frequency* f_N — The rated frequency of the supply network.

4.3.2 *Rated Voltages*

4.3.2.1 *Rated voltage on line side,* U_{LN} — The rms voltage between terminals on the line side of the transformer specified as the basis of rating for traction application.

If the line winding is provided with taps, the rated voltage shall refer to the principal tap.

4.3.2.2 *Rated voltage on cell side,* U_{vo} — The rms no-load voltage between consecutive commutating phase terminals of cell windings of a commutating group at rated voltage on the line side.

If the cell winding is provided with taps, the rated voltage shall refer to the principal tap (*see* Fig. 3).

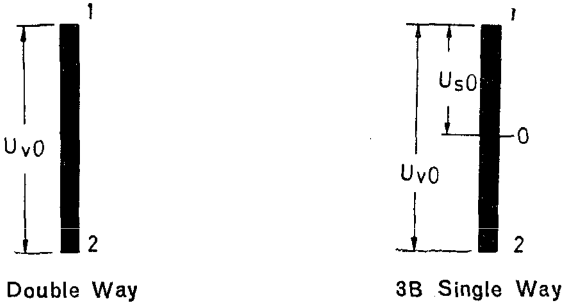


FIG. 3 DIAGRAMS OF CELL SIDE WINDINGS

4.3.3 *Rated Currents*

4.3.3.1 *Rated continuous current on the cell side,* I_{VN} — The rms current in the terminals of the transformer on the convertor side, calculated from the rated continuous direct current supplied by the convertor for traction. The calculation is based on the type of winding connection and the current ripple factor on the dc side as mutually agreed between the purchaser and the manufacturer.

4.3.3.2 Rated continuous current on the line winding (I_{LN}) corresponding to the rated continuous current on the convertor winding.

The rms current in the line terminals of the transformer calculated from the rated continuous current on the convertor winding.

4.3.3.3 *Total rated continuous line current,* I_{LGN} — The rms current in the line terminals of the transformer calculated from the rated continuous direct current supplied by the convertor for traction and allowing for the load on the auxiliary winding.

4.3.4 *Total Rated Continuous Apparent Power on the Line Side* — The product of the rated voltage U_{LN} (**4.3.2.1**) and the total rated continuous line current I_{LGN} (**4.3.3.3**) expressed in kVA.

5. ELECTRICAL CIRCUIT AND OPERATING CONDITIONS

5.1 Electrical Circuit

5.1.0 *General* — The general arrangement of electrical circuits and its protective equipment, relevant to the design of power convertors, shall be clearly indicated by the purchaser. The principal data of the equipment and circuits shall be specified generally according to Appendix B.

5.1.1 *Traction Power Circuit*

5.1.1.1 The power circuit of single phase ac traction vehicle broadly consists of :

a) a power transformer for stepping down the line voltage to traction voltages,

b) power convertor equipment and smoothing reactor for power conversion, and

c) dc traction motors.

5.1.1.2 The power transformer consists of a line winding and single or multiple cell windings. The voltage control is obtained by HT or LT tap changer. The power convertors are connected across the cell winding or windings either in single or double way connection. One or more convertors connected in series or in parallel or as independent unit, feed the individual traction motor or a group of motors connected in series parallel and/or parallel combinations. In order to limit the percentage ripple on the dc side, smoothing reactors are connected in the traction motor circuit.

5.1.2 *Protective Equipment*

5.1.2.0 Adequate protections shall be incorporated in the power circuit to limit the voltage surges and surge currents to economical limits for the power convertor design. The protective devices indicated in **5.1.2.1** to **5.1.2.5** either all or a combination of some of these and/or any other approved practice may be adopted in the design conforming to the general scheme of power/auxiliary circuits.

5.1.2.1 *Transformer protection*

a) *Main circuit-breaker* — Provided on line winding to clear the fault within a specified period.

b) *Lightning surge protection* — Lightning spark gaps provided across line winding to protect against lightning surges.

c) *Primary overload protection* — Comprising of current transformer and overload relay provided on line winding.

5.1.2.2 *Convertor overvoltage protection*

a) Surge suppression circuit across cell windings comprising of:
    1) surge arrestor to limit the surge levels to designed value of diode,
    2) R-C surge divertor to suppress switching surges, and
    3) earthing condenser to limit the steep wave front line surges reflected on cell windings.

b) Surge suppression circuit across dc output comprising of:
    1) dc damping resistive base load, or
    2) R-C damping circuit.

5.1.2.3 *Convertor overcurrent protection*

- a) Protection against external dc short circuit:
  - 1) overcurrent relay fed by current transformer in the cell winding or line winding; and
  - 2) dc overload relay in traction motor circuit.
- b) Protection against internal ac short circuit caused by convertor fault:
  - 1) bridge or a string fuse protection.

5.1.2.4 *Diode/diode-string protection*

- a) Semiconductor type fuses in the string or line to protect against failure of diode strings,
- b) Indication of fuses/diode failure, and
- c) High storage capacitors and voltage sharing network for more than one diode in series.

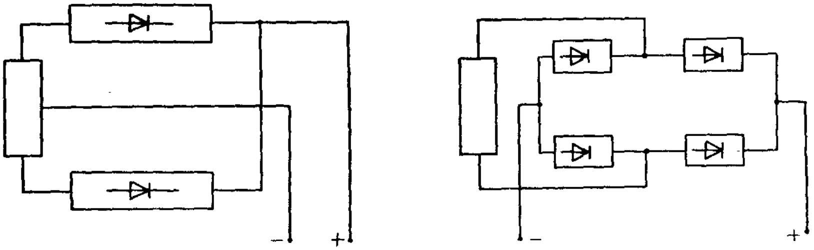
5.1.2.5 *Ventilation protection*

- a) Air flow or any other suitable type of relay to detect ventilation failure for other than naturally cooled rectifiers;
- b) overcurrent protection for blower motor set.

5.1.3 *Rectifier Circuit Arrangement* — Single-phase traction power convertors are provided with either single-way connection or double-way connection.

5.1.3.1 *Single-way connection* — Rectifiers with single-way connection are provided on transformers with mid-point cell windings. The rectifier comprises of two arms, each with one or more parallel strings, each string consisting of diode or diodes connected in series (*see* Fig. 4A).

5.1.3.2 *Double-way connection* — Rectifiers with double-way connection are provided across full cell windings. The rectifier comprises of four arms, each with one or more parallel strings, each string consisting of diode or diodes connected in series (*see* Fig. 4B).



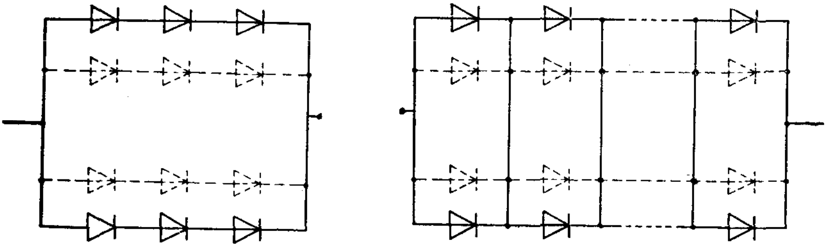
4A SINGLE WAY CONNECTION 4B DOUBLE WAY CONNECTION

FIG. 4 RECTIFIER CIRCUIT ARRANGEMENTS

5.1.3.3 *Diode arrangement* — An internal arrangement of diode in the rectifier arm is either:

a) *String connection* — an arrangement in which each parallel string, consisting of one or more diodes in series, is independent and there is no inter-connection between the parallel strings (*see* Fig. 5A); or

b) *Mesh connection* — an arrangement in which the parallel strings consisting of a number of diodes in series, are interconnected across the theoratically equi-potential diodes (*see* Fig. 5B).



5A STRING CONNECTION

5B MESH CONNECTION

FIG. 5 DIODE ARRANGEMENTS

5.2 Limits of Variation of Supply Voltage

5.2.1 *Traction Line Voltage* — The limits of line voltage shall generally conform to those given in Appendix B. The equipment shall work satisfactorily at any line voltage between 0·75 U_{LN} and 1·1 U_{LN} and shall be capable of operation for a duration of 10 seconds at voltages up to 0·7 U_{LN}. The specified operating voltage range for 25 kV single-phase ac traction is between 19·0 kV to 27·5 kV with a minimum voltage of 17·5 kV for short duration.

5.2.2 *Auxiliary Supply Voltage* — The limits of auxiliary supply voltage shall generally conform to those given in Appendix C.

5.3 Special Operating Conditions

5.3.1 Equipment covered by this specification shall be suitable for mounting on the power vehicle and unless otherwise specified shall satisfactorily withstand the service conditions specified under **3**.

5.3.2 Forced ventilated power convertors drawing air from inside the equipment compartment of vehicle and discharging it in free atmosphere shall be adequately rated for operation with a depression up to 25 mm of water. In case, the air inlet and outlet are at the same atmospheric pressure, no special consideration is to be given for depression inside the vehicle.

5.3.3 Cooling equipment for power convertors shall be adequately rated to meet the design requirements under minimum line voltages given in **5.2** and under worst climatic conditions as specified in **3**.

5.3.4 Power convertors, provided with cell failure indicating device, shall be capable of normal operation with the failure of a single diode.

5.3.5 Unless otherwise specified, power convertors provided with string fuse protections, shall be adequately rated for normal operation of vehicle with one string fuse eliminated, meeting the specified duty cycle requirements.

5.3.6 When the power convertor unit consists of more than one convertor sets in parallel, the operating conditions of power vehicle with half or partial unit eliminated shall be clearly specified by the purchaser.

6. CONSTRUCTION

6.1 Mechanical Construction

6.1.1 The size and mounting location of convertor cubicle is governed by the general layout of other traction equipment on the vehicle. The overall dimensions and mounting arrangements of the cubicle shall be clearly specified by the purchaser.

6.1.2 The mechanical construction of power convertor cubicle shall generally conform to IS : 6619-1972* suitably modified for traction application, wherever necessary. Any modification shall be subject to agreement between the manufacturer and the purchaser.

6.1.3 The general recommendations for mechanical construction are given in Appendix D.

6.2 Electrical Construction — The general recommendation for electrical construction are given in Appendix E.

6.2.1 All major electrical equipment used for fabrication of convertor assembly, namely, blower motor, contactors, relays, switches, protective equipment, etc, shall be of robust construction and design to meet the traction requirements. These shall be clearly marked to indicate its type, nomenclature and rating. Wherever the equipment is being used for the first time for this application, type test shall be conducted as mutually agreed between the purchaser and the manufacturer before its acceptance.

6.2.2 The electrical construction of convertor cubicles shall generally conform to IS : 732-1963† and IS : 2274-1963‡, wherever applicable.

---

*Safety code for semiconductor rectifier equipment.

†Code of practice for electrical wiring installations (system voltage not exceeding 650 volts) (*revised*).

‡Code of practice for electrical wiring installations (system voltage exceeding 650 volts).

7. PERFORMANCE REQUIREMENTS

7.0 General — The performance requirements of traction power convertor shall be clearly specified by the purchaser, indicating the maximum limiting conditions obtainable in service. Since the thermal time constant of semiconductor devices and its assembly is small and these are susceptible to damages due to transient voltage and current surges, the performance requirements with regard to both continuous and transient conditions for voltage and current ratings shall be specified. The requirements with regard to transient conditions may, however, normally determine the size and diode series-parallel arrangement in the convertor assembly.

7.1 Voltage Rating — The convertor assembly shall be designed for number of cells in series based on voltage ratings of:

a) maximum repetitive voltage of the circuit,

b) maximum switching surges, and

c) lightning surges.

7.1.1 *Maximum Repetitive Voltage* — It shall generally be taken as maximum open-circuit voltage at the last transformer tap and at maximum line voltage.

7.1.2 *Switching Surges* — Switching surges equal to 200 percent of maximum no-load voltage shall generally be assumed for the design unless these are much below the specified protection level of the convertor surge arrestor.

7.1.3 *Lightning Surges* — The level of lightning surges appearing on cell winding shall correspond to the characteristics of spark gaps provided on line winding. The transmissibility factor of steep wave-front surges is determined by the transformer construction and may be assumed as 90 percent of primary to secondary transformation ratio unless otherwise specified by the manufacturer.

7.2 Current Rating — The convertor assembly shall be designed for a number of cells in parallel based on current ratings of :

a) continuous accelerating current or its equivalent continuous duty,

b) starting duty cycle,

c) specified short-circuit current and its duration.

7.2.1 *Continuous Accelerating Current* — The continuous rating of convertor shall generally be taken as the mean of the maximum accelerating or starting current of the vehicle unless otherwise specified by the purchaser. If the specified accelerating current and its duration are such that the design can be made economical by utilising short-time rating of convertor, the specified equivalent continuous duty shall be mutually agreed between the purchaser and the manufacturer.

7.2.2 *Starting Duty Cycle* — The starting duty cycle shall be specified preferably with the help of a diagram, indicating the current values and its duration and the period of rest, if any. The convertor shall normally be designed to meet the requirements of starting duty cycles even under conditions of a single diode failure or a string failure as indicated under **5.3.4** and **5.3.5**.

7.2.3 *Short-Circuit Rating*

7.2.3.1 The power convertor shall normally be designed for the fault level corresponding to traction motor flashovers, namely, short circuit across dc output with smoothing reactor in the circuit. This shall generally correspond to the limiting values of line voltage and transformer tap unless otherwise specified. In case the limiting values are appreciably higher than those obtainable under normal operating conditions, the level of short-circuit current and its duration shall be mutually agreed between the purchaser and the manufacturer.

7.2.3.2 Direct short-circuit current across dc bus bar is generally not catered for since the fault level with low transformer impedance may be too high for an economical convertor design. Internal short circuit due to diode/diode-string failure shall, however, be taken into consideration, while designing convertor fuse protections.

7.3 Voltage Distribution for Series Connected Diodes — Unequal voltage distribution may be caused by the difference in reverse voltage characteristics of diodes connected in series and shall be specified by the manufacturer. In case convertor equipments are intended for series operation, the voltage unbalance between the units shall also be specified. A minimum voltage unbalance of 10 percent shall be assumed for the design unless otherwise specified.

7.4 Current Distribution for Parallel Connected Diodes — Unequal current distribution may be caused by difference in forward voltage characteristics of diodes connected in parallel strings and shall be specified by the manufacturer. In case convertor equipment are intended for parallel operation, the current unbalance between the units shall also be specified. A minimum current unbalance of 10 percent shall be assumed for the design, unless otherwise specified.

7.5 Cooling Air Temperature — The power convertor installed inside traction vehicle shall generally be designed for a cooling air inlet temperature of 60°C. A further temperature rise of 15°C may be assumed in the convertor duct for determining the maximum junction temperature of the hottest cell, unless otherwise stated by the manufacturer.

8. TECHNICAL DATA

8.1 Application Data for Convertor Design — The application data relevant to the design of power convertor shall clearly specify the limiting performance requirement as specified in **7**. The data given by the purchaser shall generally conform to Appendix F.

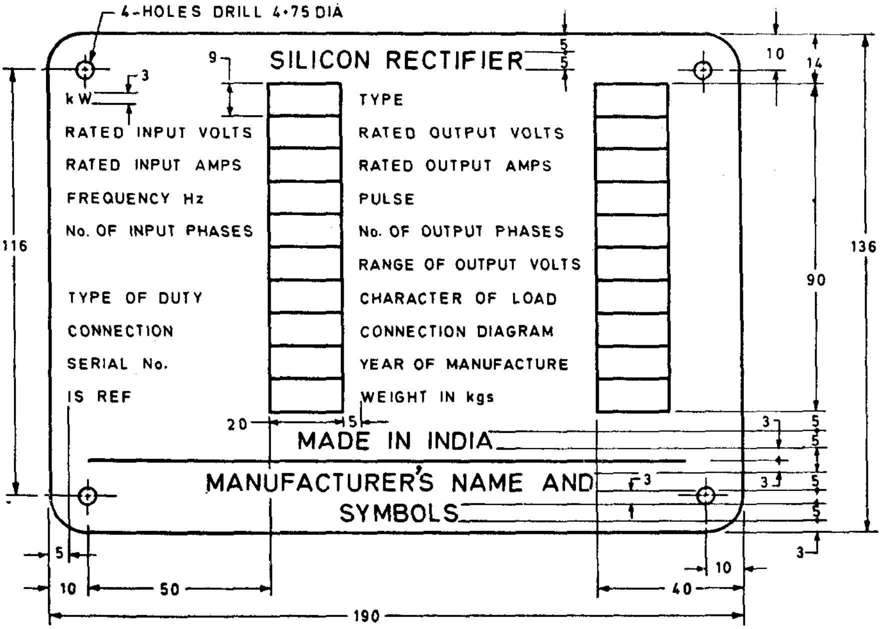
8.2 Technical Data of Convertor Assembly — The technical data of diode and convertor assembly shall be furnished by the manufacturer generally as given in Appendix G.

9. MARKING

9.1 The convertor assembly shall be provided with rating plate, giving the following information:

a) Rated kW,
b) Rated input voltage,
c) Rated input current,
d) Frequency
e) No. of input phases,
f) Type of duty,
g) Type,
h) Rated output voltage,
j) Rated output current,
k) Pulse,
m) No. of output phases,
n) Character of load,
p) Connection,
q) Connection diagram,
r) Year of manufacture,
s) Weight in kg,
t) Serial No,
u) Country of manufacture,
v) Ref to this Indian Standard specification, and
w) Name of manufacturer.

9.1.1 The arrangement of the information given on the rating plate shall be as given in Fig. 6.



All dimensions in millimetres.

FIG. 6 RATING PLATE DETAILS

9.2 The convertor assembly may also be marked with the ISI Certification mark.

NOTE — The use of the ISI Certification Mark is governed by the provisions of the Indian Standards Institution (Certification Marks) Act and the Rules and Regulations made thereunder. The ISI Mark on products covered by an Indian Standard conveys the assurance that they have been produced to comply with the requirements of that standard under a well-defined system of inspection, testing and quality control which is devised and supervised by ISI and operated by the producer. ISI marked products are also continuously checked by ISI for conformity to that standard as a further safeguard. Details of conditions under which a licence for the use of the ISI Certification Mark may be granted to manufacturers or processors, may be obtained from the Indian Standards Institution.

10. TESTING

10.0 General — Type and routine tests on diodes and convertor assembly shall be carried out under the specified limiting conditions used by the manufacturer as the basis for assigning rated values and characteristics. Type tests shall be carried out on a specified number of equipment of a given type.

Number and periodicity of the test samples drawn from a batch of production shall be as mutually agreed to between the purchaser and the manufacturer. In general, routine tests shall be conducted on each equipment.

NOTE — Type tests and routine tests carried out by the diode manufacturer need not be repeated by the equipment manufacturer. The results of the type tests shall be made available to the equipment manufacturer and through him to the ultimate purchaser on request.

10.0.1 *Classification of Tests*

10.0.1.1 Tests are classified as follows:

a) Type tests,
b) Routine tests, and
c) Investigation tests.

The difference between these three categories of tests is brought out in **10.0.1.2** to **10.0.1.4**.

10.0.1.2 *Type tests* — Type tests shall be carried out to verify that a product will meet the requirements specified and agreed between the user and the manufacturer.

Type tests shall be performed on a single unit of a given design and manufacturing procedure.

If a complete convertor or an individual component of it is identical with or similar to one previously tested, the manufacturer may supply a certificate of previous tests on it which shall at least cover the contract requirements. In such cases, unless otherwise agreed, it is not necessary to repeat these tests on the unit under consideration.

Some or all of these tests may be repeated from time to time on samples drawn from current production or deliveries, so as to confirm that the quality of the product still meets the requirements specified.

Optional type tests are only to be carried out if they are particularly specified in the contract.

10.0.1.3 *Routine tests* — Routine tests are carried out to verify that the properties of a product correspond to those measured on the type test. Routine tests shall be performed by the manufacturer, in principle, on each one of several devices or equipment of the same type.

However, the certificates of the manufacturer's tests presented to him during the routine tests may be taken as valid by the user. The user may then check by random sampling the results of the manufacturer's tests without having to repeat these tests on every unit.

Optional routine tests are to be carried out only if they are particularly specified in the contract.

10.0.1.4 *Investigation tests* — Investigation tests, the object of which is to obtain additional information on methods of using the convertor, may be arranged at the special request of the user or the manufacturer. The performance of these tests is required only if they are specified in the contract.

The results of investigation tests may not be used as grounds for refusing acceptance of the equipment or to invoke penalities.

10.1 Tests on Diodes

10.1.1 Type and routine tests on diodes shall be carried out in accordance with Table 1.

NOTE — In addition to the tests specified in Table 1, diode stacks supplied separately shall be submitted to an insulation test in accordance with IS : 3895-1966*. If necessary, this test may be carried out in accordance with **10.2.9**.

TABLE 1 TESTS ON DIODES

SL No.	NATURE OF TESTS	CLAUSE NUMBER	
		Type Tests	Routine Tests
i)	Forward voltage	10.1.2.1	10.1.2.2
ii)	Reverse characteristic	10.1.3	—
iii)	Reverse current	10.1.4	10.1.4
iv)	Reverse voltage	10.1.5	10.1.5
v)	Reverse recovery charge	10.1.6	—
vi)	Thermal resistance	10.1.7.1	10.1.7.1
vii)	Transient thermal impedance	10.1.7.2	—
viii)	Thermal cycling	10.1.8	—
ix)	Surge forward limit current	10.1.9.1	10.1.9.2
x)	Surge forward current	10.1.10	—
xi)	Load	10.1.11	—
xii)	Deterioration	10.1.12	—
xiii)	Encapsulation	10.1.13	10.1.13

10.1.2 *Forward Characteristic Test*

10.1.2.1 *Forward voltage test—ac method (preferably used for type tests)* — The forward voltage instantaneous values shall be recorded for the full current range in a circuit giving a forward current wave shape corresponding to a single phase connection with resistive load.

---

*Specification for monocrystalline semiconductor rectifier cells and stacks.

The test shall be carried out at the maximum junction temperature of the diode specified by the manufacturer.

A measuring circuit is given in Fig. 7.

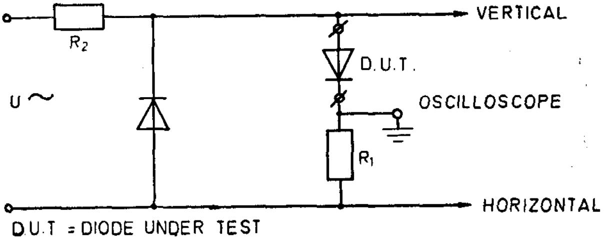


FIG. 7 CIRCUIT FOR FORWARD VOLTAGE TEST BY ac METHOD

10.1.2.2 *Forward voltage test — pulse method (preferably used for routine test)* — This method allows a measurement of the forward voltage under the condition of negligible internal heating or at a current level that would damage the diode if maintained continuously.

A measuring circuit is given in Fig. 8.

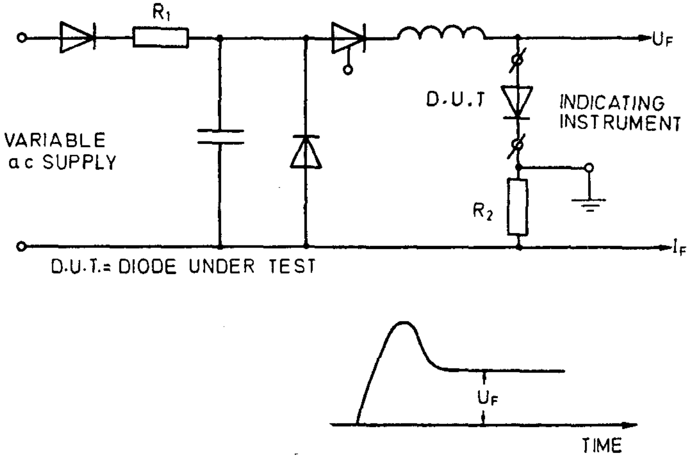


FIG. 8 CIRCUIT FOR FORWARD VOLTAGE TEST BY PULSE METHOD

The duty cycle of the current pulse, the repetition frequency and the virtual junction temperature shall be as specified.

The test is performed by measuring the peak forward voltage corresponding to the peak forward current. The test current pulse width shall be wide enough to ensure that the tested device has obtained its steady state (pulse width of 3 to 4 milliseconds is generally sufficient). The duty cycle and repetition rate are to be such that internal device heating is negligible.

The capacitor is charged to the peak of the ac supply voltage. On the next half cycle of the supply voltage, the thyristor is triggered which results in the capacitor discharging through the inductor and under test device. The test current may be sensed across a small value non-inductive resistor R_2.

10.1.3 *Reverse Characteristic Test* — The reverse characteristic shall be recorded in a circuit giving a reverse voltage corresponding to a single phase connection at no-load and the values shall be within the limits specified by the manufacturer.

The measurements shall be carried out at rated repetitive peak reverse voltage and at a specified maximum virtual junction temperature.

A circuit to measure the reverse characteristic is given in Fig. 9.

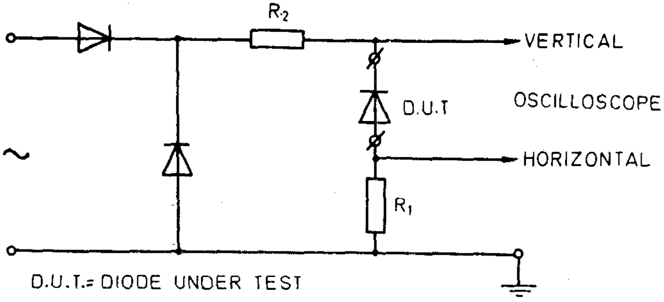


FIG. 9 CIRCUIT FOR REVERSE CHARACTERISTICS TEST

10.1.4 *Reverse Current Test* — Each diode shall withstand, without injury, a half-wave sinusoidal voltage having a peak value, measured across the diode, equal to the repetitive peak reverse voltage. The instantaneous reverse current shall be within the specified limits.

The test shall be performed at maximum virtual, junction temperature. This temperature may be obtained at the option of the manufacturer by any of the following methods:

a) By raising the diode temperature, at no load, to the declared virtual junction temperature; and

b) By applying forward current under conditions of ambient temperature and cooling to obtain rated maximum virtual junction temperature in a circuit that will apply rated repetitive peak reverse voltage during the negative period.

10.1.5 *Reverse Voltage Test* — Each diode shall be subjected to one half cycle sinusoidal voltage having a peak value, measured across the diode, equal to the rated maximum non-repetitive peak reverse voltage.

The test shall be performed at maximum virtual junction temperature. A suitable test circuit is shown in Fig. 10.

The thyristor is turned on by one sirgle gate pulse at the beginning of a half cycle of the alternating supply voltage.

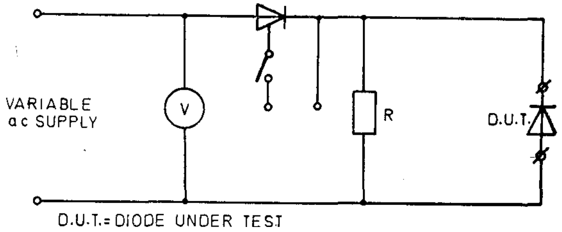


FIG. 10 CIRCUIT FOR REVERSE VOLTAGE TEST

10.1.6 *Reverse Recovery Charge Test* — A suitable test circuit for measuring reverse recovery characteristics is shown in Fig. 11 along with the test current waveform. Recovery time and recovery charge as well as recovery current can be measured by means of this circuit.

The test current waveform is produced by charging capacitor *C* during one half cycle of the input voltage and then on the next half cycle triggering the thyristor to discharging *C* through inductor *L* and the under test device. Non-inductive current sensing resistor *R* is made extremely small so that the values of *L* and *C* determine the characteristics of the test current.

The test conditions are:

a) Peak forward current I_{FM};

b) Rate of reversal of forward current (di/dt) measured from 50 percent I_{FM} to $i_F = 0$;

c) Base width of forward current pulse;

d) Test repetition rate (duty factor 1 percent); and

e) Virtual junction temperature of test device.

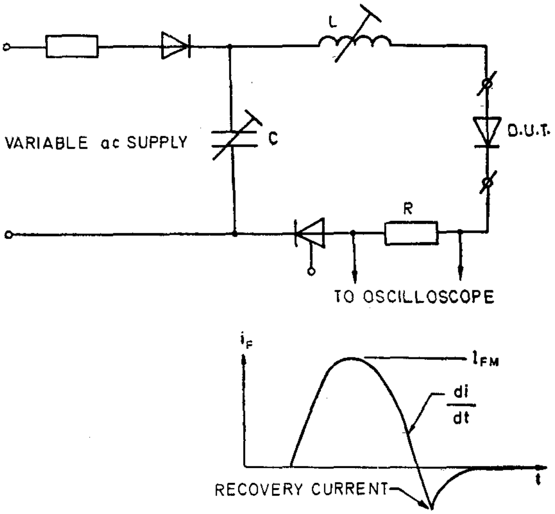


FIG. 11 CIRCUIT FOR REVERSE RECOVERY CHARGE TEST

10.1.7 *Thermal Resistance and Transient Thermal Impedance Test*

10.1.7.0 *General* — The measurement of thermal resistance and transient thermal impedance is based on the use of a temperature-sensitive parameter as an indicator of virtual junction temperature. The forward voltage of the diode at a small percentage of maximum mean forward current is normally used as the temperature-sensitive parameter.

10.1.7.1 *Thermal resistance* R_{th}

$$R_{th} = \frac{\phi_2 - \phi}{P_2 - P_1}$$

where

R_{th} = thermal resistance,
ϕ = reference point temperatures, and
P = power dissipation.

Power P_1 is applied, and the reference point temperature ϕ_1 is measured, using values of power and temperature within the device ratings.

The power P_1 is interrupted to permit measurement of the virtual junction temperature by means of the forward voltage of the diode with a reference current flowing immediately after the interruption of P_1.

Power P_2 is then applied, and the device is heated externally until the same value of virtual junction temperature is obtained. ϕ_2 is then measured.

NOTE — The power applied should be either dc or of a sufficiently high frequency that the fluctuation of the virtual junction temperature is negligible. The measurement of forward voltage of the diode should be made at a time following the power interruption(s) such that the non-thermal transients have decayed, but before the change of virtual junction temperature is significant.

10.1.7.2 *Transient thermal impedance* $Z_{(th)t}$ — A calibration curve is prepared for the device by measuring the forward voltage of the diode at the selected value of measuring current, as a function of virtual junction temperature, by varying the device temperature externally for example by means of an oil-bath (*see* Fig 12).

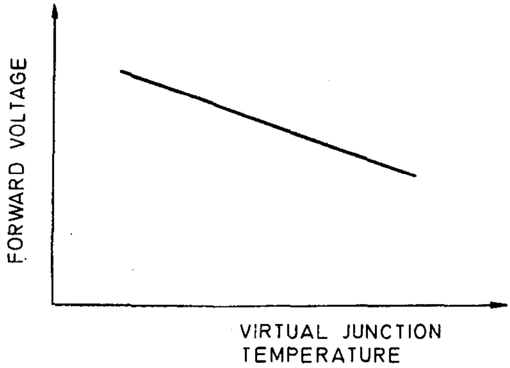


FIG. 12 FORWARD VOLTAGE AND VIRTUAL JUNCTION TEMPERATURE CHARACTERISTIC

A measuring circuit as shown in Fig. 13 may be used to obtain the data required for calculating the transient thermal impedance characteristic curve. After applying the heating current and waiting until thermal equilibrium is established, the power dissipated in the device is measured and recorded. The heating current supply is then interrupted, and the forward voltage of the diode corresponding to the measuring current supply is recorded as a function of time, as shown in Fig. 14. This may be accomplished by photographing the oscilloscope trace. The measurement may be repeated at different oscilloscope sweep rates in order to measure adequately the forward voltage of the diode over the entire time range. Reference point temperature should be monitored as a function of time. Since this change is relatively small and slow, a thermistor or thermocouple measuring system should be adequate.

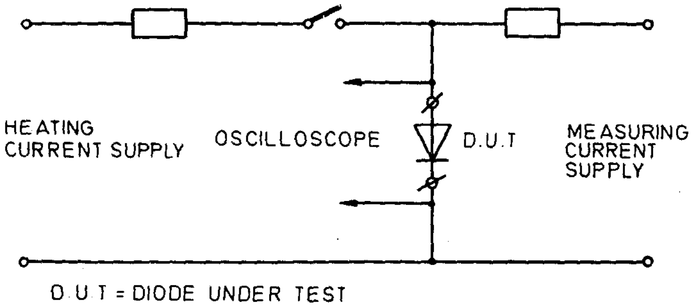


FIG. 13 CIRCUIT FOR OBTAINING TRANSIENT THERMAL IMPEDANCE CHARACTERISTIC CURVE

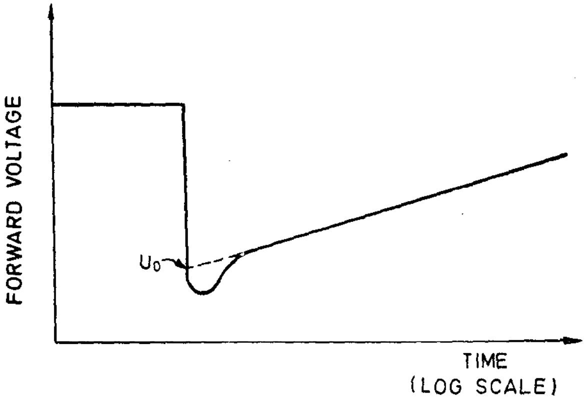


FIG. 14 FORWARD VOLTAGE AND TIME CHARACTERISTICS

The curve of forward voltage as a function of time can be converted to virtual junction temperature *versus* time by means of the calibration curve. Transient thermal impedance is calculated as follows:

$$Z_{(th)t}\,(t) = \frac{(A - B) - (A' - B')}{P}$$

where

A = the virtual junction temperature at the time of heating current interruption;

A' = virtual junction temperature at time 't' seconds after heating current interruption;

P = power dissipated in the device;

B = reference point temperature at the time of heating current interruption;

B' = reference point temperature at time ' t ' seconds after heating current interruption;

$Z_{(th)t}\ (t)$ = transient thermal impedance at time ' t '.

10.1.7.3 *Precautions* — Difficulties with this measurement method are due to ambiguity in determining the value of virtual junction temperature at the time of current interruption.

Non-thermal voltage transients occur due to the excess charge carriers present after the heating current is interrupted. This difficulty can be avoided by extrapolating the forward voltage *versus* time curve back to zero time from a time at which the device is known to be in charge equilibrium. This time can be estimated from life time observation or by performing the measurements at different power levels and noting the shortest time for which the virtual junction temperature is a linear function of power dissipation. The dotted portion of the forward voltage curve in Fig. 14, illustrates the extrapolation to the point shown as U_0.

Another source of non-thermal transients in the forward voltage characteristics is due to the collapse of the magnetic field around the device when the heating current is interrupted. An example of where this problem may be significant is when currents of 10A or more are used with diodes housed in packages having a magnetic material encircling the conductor. Decay times of the order of one-half to one millisecond have been observed due to this phenomenon.

10.1.8 *Thermal Cycling Test* — The manufacturer shall provide evidance by a type test, or by other means acceptable to the purchaser, to show that the diode will be able to withstand without injury or significant change of thermal resistance or significant increase of forward voltage drop or of reverse current, long-term thermal cycling adequate to meet the needs of railway service. In this thermal cycling the temperature is varied through an excursion (that is difference between cyclic maximum and minimum temperatures) at least as great as can occur in the load cycle in any condition of operation in service which complies with the requirements of this standard.

A test circuit is given in Fig. 15.

The diode shall be heated by a specified current not less than the maximum mean forward current, until the maximum specified virtual junction temperature has been reached. Then the switch SK_1 is opened and the diode is cooled to a specified low temperature, not exceeding 50°C.

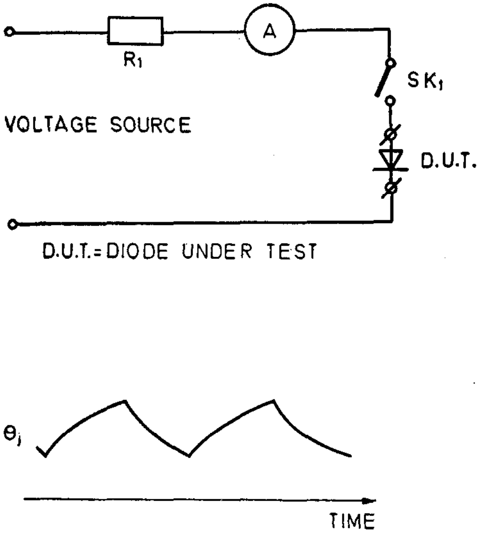


Fig. 15 Circuit for Thermal Cycling Test

The cycle duration depends on the cooling method and shall be specified.

The temperature excursion shall be applied at a rate of not less than one cycle every five minutes and not more than one cycle every two minutes and the on/off ratio shall be not less than 0·9 to 1 and not more than 1·1 to 1.

All parameters that may be affected by the test shall be measured before and after the test to check that no appreciable change has occurred during the thermal cycling.

10.1.9 *Surge Forward Limit Current Test (With No Reverse Voltage)* — The test is performed by subjecting diodes to forward surge current 50 Hz half sine-wave pulses followed by no reverse voltage applied during the other half non-conducting period. The peak values of current, the number of cycles and the test junction or base temperature shall be in accordance with the manufacturer's declared values. After the test there shall be no detectable change in the diode characteristics.

10.1.9.1 *Type test* — During the test the current pulse, its duration and virtual junction or base temperature shall be recorded. The type test on diodes shall be conducted at the specified maximum junction temperature and at various surge forward limit current peak values specified for 1 to 8 cycles namely 10 ms to 150 ms.

10.1.9.2 *Routine test* — The routine test on diode shall be conducted in a similar manner as above, but only for surge forward limit current peak value specified for 10 ms. The diode shall be subjected to 100 pulses at the rate of 1 pulse per minute.

10.1.10 *Surge Forward Current Test (With Reverse Voltage)* — This test shall be performed by passing a specified number of 50 Hz half sine-waves of surge current through the test device with specified 50 Hz half cycle reverse voltage applied between the current pulses. Half cycle reverse voltage may be applied for a specified time before and after the surge current test interval. After the test there shall be no detectable change in diode characteristics.

The test conditions to be specified are:

a) peak half sine-wave surge current;
b) peak half sine-wave reverse voltage equal to 50 percent rated repetitive peak reverse voltage;
c) number of half cycles of surge current;
d) duration of reverse voltage before and after current surges; and
e) maximum virtual junction temperature of test device.

A suitable test circuit is shown in Fig. 16.

Thyristor T_1 is triggered at the beginning of the proper half cycle of the ac supply to produce a half cycle of surge current. Thyristor T_2 is triggered just slightly after the start of the next half cycle of the ac supply in order to apply half cycle reverse voltage to the test device. The trigger delay is to ensure that thyristor T_1 will be off before reverse voltage is applied.

10.1.11 *Load Test* — This test shall be carried out to verify that a diode type can withstand indefinitely the specified maximum continuous loading.

The load test shall be carried out for a period of 1 000 hour. This test is performed by passing specified 50 Hz half sine-wave current through the test device, with specified 50 Hz half sine-wave voltage applied on alternate half cycles. The recommended test circuit, test current and voltage waveforms are shown in Fig. 17.

Thyristor T_1 is triggered at the beginning of the proper half cycle of the ac supply in order to initiate the test current. Thyristor T_2 is triggered just slightly after the start of the next half cycle of the ac supply in order to initiate the test voltage. The trigger delay is to ensure that thyristor T_1 will be off before the test voltage is applied.

The test conditions to be specified are:

a) test current magnitude;
b) test voltage magnitude;
c) duration of test; and
d) reference point temperature of test device.

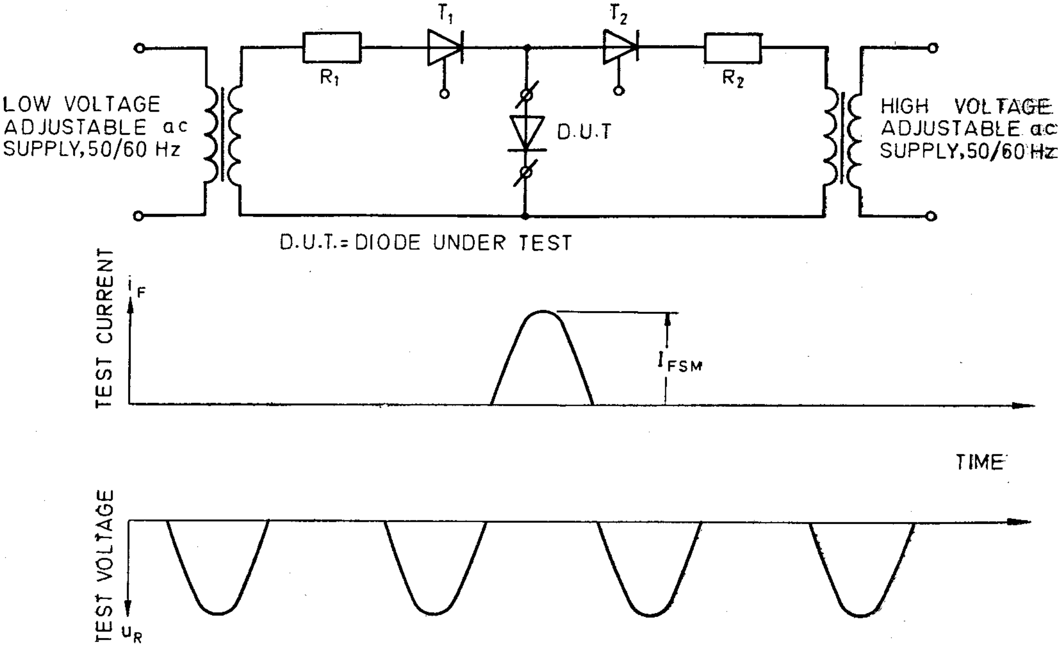

T₁
T₂
R₁
R₂
LOW VOLTAGE ADJUSTABLE ac SUPPLY, 50/60 Hz
D.U.T
HIGH VOLTAGE ADJUSTABLE ac SUPPLY, 50/60 Hz
D.U.T. = DIODE UNDER TEST
TEST CURRENT
i_F
I_{FSM}
TIME
TEST VOLTAGE
u_R

Fig. 16 Circuit for Surge Forward Current Test

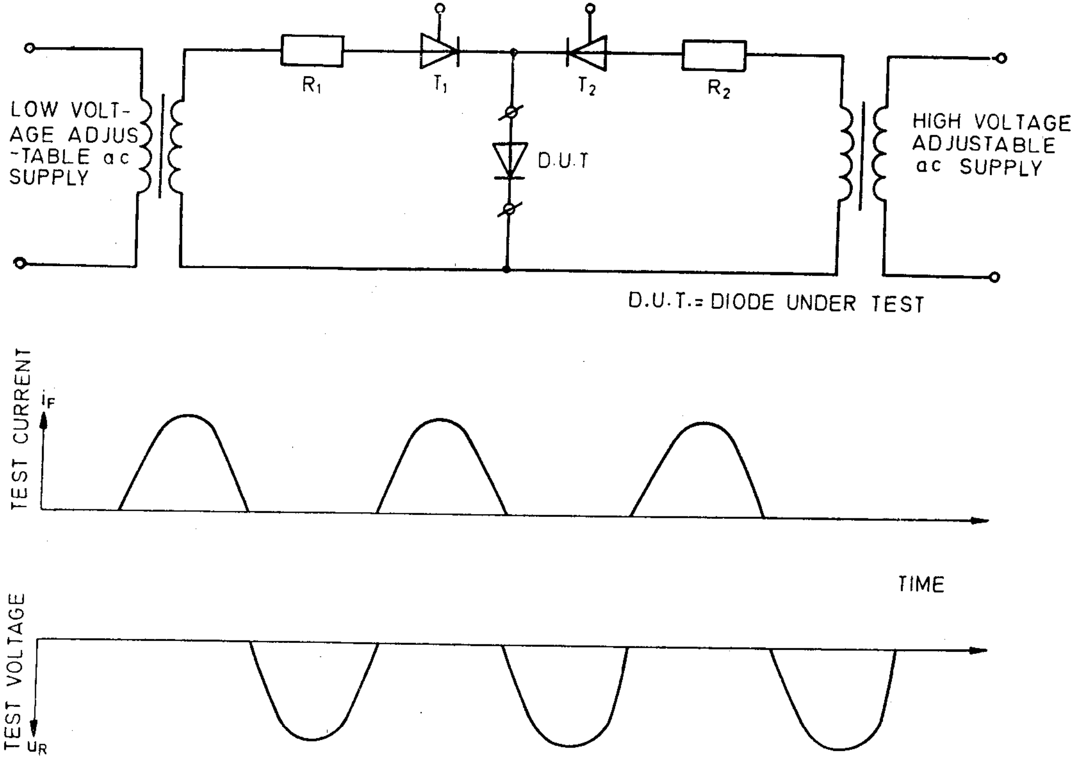

LOW VOLTAGE ADJUSTABLE ac SUPPLY
R_1
T_1
T_2
R_2
D.U.T
HIGH VOLTAGE ADJUSTABLE ac SUPPLY
D.U.T. = DIODE UNDER TEST
TEST CURRENT
i_F
TIME
TEST VOLTAGE
u_R

Fig. 17 Circuit for Load Test

10.1.12 *Deterioration Test* (*Investigation Test*) — The diodes shall be maintained for a total period of at least one month at the maximum specified junction temperature. After this period the reverse current at 80 percent of the rated non-repetitive peak reverse voltage (PTV) shall:

a) not exceed the maximum specified reverse current at PTV, and
b) shall be not more than 1·5 times the original recorded value before the test.

The number of diodes to be subjected to these tests shall be mutually agreed between the purchaser and the manufacturer.

10.1.13 *Encapsulation Test* — The completed diode without any protective coating shall be subjected to an approved test to show that no detectable leakage of gas takes place between the atmosphere and the interior of the diode.

The test may be conducted by helium detector or by immersion of diode in hot oil-bath at a specified temperature for a given duration.

10.2 Tests on Convertor Assemblies

10.2.1 Type and routine tests on convertor assemblies shall be carried out in accordance with Tables 2 and 3.

TABLE 2 TESTS ON CONVERTOR ASSEMBLY

Sl No.	Test	Clause Number	
		Type Tests	Routine Tests
i)	Ventilation	10.2.2	—
ii)	Mechanical vibrations and shock	10.2.3	—
iii)	Voltage sharing	10.2.4	10.2.4
iv)	Forward current sharing	10.2.5	10.2.5
v)	Continuous duty temperature-rise	10.2.6	10.2.6
vi)	Starting duty cycle temperature-rise	10.2.7	—
vii)	Impulse voltage	10.2.8	—
viii)	Insulation	10.2.9	10.2.9
ix)	Tests on convertor assemblies	10.2.10	10.2.10
x)	Tests on indicating and functional units of convertor assemblies	10.2.11	10.2.11
xi)	Power loss measurement	10.2.12	—
xii)	Check of diode characteristic	10.2.13	—

TABLE 3 TESTS ON CONVERTOR ASSEMBLY AFTER INSTALLATION ON VEHICLE

(*Clause* 10.2.1)

SL No.	TEST	CLAUSE NUMBER	
		Type Test	Routine Test
i)	After installation on vehicle	10.2.14	10.2.14
ii)	Simulated traction motor flashover	10.2.15	—
iii)	AC circuit-breaker switching	10.2.16	—

10.2.2 *Ventilation Tests*

10.2.2.1 Ventilation tests shall be carried out at the ambient temperature in order to measure the air-flow passing through the various components cooled by forced ventilation. In case of other cooling methods suitable measurements shall be made as agreed between the manufacturer and the purchaser.

If the blower set or sets form part of the convertor assembly, the blower shall be run at a voltage corresponding to the rated volage U_{LN} (*see* **4.3.2.1**) and at 0·75 U_{LN} and measurements is made of air flow, air pressure and motor speed. The minimum ventilation specified by the manufacturer for the convertor assembly shall be available at 0·75 U_{LN}. After the test the voltage shall be reduced to 0·7 U_{LN} and the blower motor shall not stop.

If, however, the blower sets do not form a part of the convertor assembly, the test shall be carried out with a suitable blower set, the delivery from which shall be adjusted so as to obtain an air flow equal to that specified by the manufacturer for convertor assembly.

10.2.2.2 As may be necessary, tests shall also be carried out to check the effectiveness of the means provided on the convertor assembly to reduce the intake of dust, snow and water. The methods of performing these tests shall be as agreed between the purchaser and the manufacturer.

10.2.3 *Mechanical Vibrations and Shock Tests*

10.2.3.1 Subsequent to routine tests the complete convertor assembly — or one of its sub-assemblies, as agreed between the purchaser and the manufacturer — equipped with its auxiliaries and any shock absorbing devices shall be subjected to a series of the following tests. The method of testing shall be as agreed between the manufacturer and the purchaser.

a) *Determination of resonant frequencies* — In order to determine the possible existence of critical frequencies producing resonance, the frequency shall be varied progressively over the whole range mentioned in **3.1.3** within a time of not less than 4 minutes, the amplitude of the oscillations being that indicated as a function of the frequency.

If resonance is produced, the corresponding frequency shall be maintained for a few minutes in each case.

b) *Tests with sustained vibration* — The assembly is next submitted to a test with sustained vibration for a time not less than 15 minutes at any of the following frequency to be agreed between the purchaser and the manufacturer:

   a) Either at the critical frequency, if any, such well defined frequency has been detected in the course of test of **10.2.3.1** (a),

   b) otherwise at a frequency of 10 Hz,

   In both cases, the amplitude of the vibrating table is adjusted to the value corresponding to the frequency concerned (*see* **3.1.3**).

   Subject to agreement between the purchaser and the manufacturer the assembly on full load may be subjected to sustained vibration for a longer period (25 to 50 hours).

c) *Tests to simulate the effect of shunting shocks* — In the direction corresponding to the longitudinal movement of the vehicle on which it is to be mounted, the assembly shall be submitted to a series of three successive shocks each corresponding to a maximum acceleration of 3 g.

d) *Results of tests* — The tests are considered to be satisfactory if there is no resulting damage or abnormality in operation. The assembly under test shall be able to withstand successfully the routine electrical tests.

10.2.3.2 However, during these tests, the convertor assembly or sub-assembly shall remain inoperative.

10.2.4 *Voltage Sharing Test* — After checking the electrical connection of convertor assembly, ac voltage equal to 1·1 × U_{VO} (*see* **4.3.2.2**) shall be applied to the assembly for at least 5 minutes to verify that it is capable of withstanding voltages likely to be encountered in service. The voltage distribution of series connected diodes and the direct voltage shall then be recorded at the rated voltage (U_{VO}).

The test shall be conducted at ambient temperature and during the test the convertor shall be connected to a nominal load necessary to avoid any rise of the direct voltage at no-load.

10.2.5 *Forward Current Sharing Test* — With normal specified ventilation to the convertor cubicle, the dc output terminals shall be short-circuited through an ammeter shunt and the ac input voltage shall be raised until the dc load current reaches the maximum value specified in **7.2.1**.

The current in each of the strings shall be measured so as to check that the current does not exceed the average value of forward current specified for the diodes. The method of measurement shall be such that it has no appreciable effect on the current sharing. If the convertor assembly is provided with means for detecting unsatisfactory current sharing, the operation of this equipment shall also be checked during the test.

NOTE — The test may be carried on sub-assemblies also, if agreed between the purchaser and the manufacturer.

10.2.6 *Continuous Duty Temperature-Rise Tests* — The temperature rise test on convertor assembly shall be conducted with the specified cooling corresponding to the minimum auxiliary voltage of 0·75 U_{LN}. The test may be conducted at low ac input voltages, with the convertor dc output terminals short-circuited, similar to current sharing test (*see* **10.2.5**).

Several thermocouples or any other suitable transducers shall be mounted on the bodies of those diodes which are liable to give maximum temperature rise. At the start of the test, the convertor shall be subjected to nominal loads to select a few particular diodes with maximum readings for final recording of temperatures. The convertor shall then be loaded to the maximum specified value of current (*see* **7.2.1**) for a period till diodes have attained a steady state temperature. At the end of the test, readings of these thermocouples together with the temperatures of cooling air at the convertor assembly intake and exit shall be recorded. The temperatures of bus bars and other electrical joints shall also be measured and these shall not exceed the specified limits for the associated insulating materials. This should generally not exceed the recommended limit of 100°C.

The test shall be carried out at the ambient temperature. The readings obtained during the test shall be suitably corrected for:

a) the maximum service temperature, and

b) the temperature gradient of cooling air in the convertor assembly.

The recorded temperature of hottest diode shall be increased in accordance with the above by a quantity equal to the differences between:

a) specified maximum air temperature and the test ambient temperature, and

b) recorded cooling air exit temperature and interpolated air temperature at the hottest diode.

The corrected temperature of diode shall at no time exceed the maximum temperature specified by the manufacturer.

10.2.7 *Starting Duty Cycle Temperature-Rise Test* — The test shall be conducted similar to continuous duty test (*see* **10.2.6**) but with the specified duty cycle given under **7.2.2** and for special operating duties specified under **5.3.4** to **5.3.6**.

Details of these tests shall be mutually agreed to between the purchaser and the manufacturer.

10.2.8 *Impulse Voltage Test* — If to meet special operating conditions an impulse voltage test has been specified in the contract for the convertor assembly, the methods of carrying out this test shall be agreed to between the user and the manufacturer.

10.2.9 *Insulation test*

10.2.9.1 *Measurement of insulation resistance* — Before conducting dielectric test (**10.2.9.2**) the insulation resistance of convertor assembly shall be measured. All ac and dc terminals of the convertor assembly shall be joined together electrically and diode short-circuited. Measurements shall be made with a suitable meggar at voltages equal to:

a) 2 500 V for power circuits above 500 V rms, and

b) 1 000 V for auxiliary circuits below 380 V rms.

10.2.9.2 *Dielectric test*

a) *General* — Dielectric tests shall be carried out with alternating current on every single piece of apparatus, then on the equipment when mounted on the vehicle. In certain cases, to be agreed to between the user and the manufacturer, they may also be carried out on assemblies of equipment connected in groups.

The tests shall be carried out at the normal temperature of the test site.

The test voltage at a frequency of 50 Hz or 60 Hz shall be of approximately sinusoidal form and shall be applied for a period of one minute.

The methods of test and the rms values of the test voltage shall be as given in the relevant clauses.

NOTE — In all the formulae giving test voltages, U represents the supply voltage of the circuit in which the apparatus subject to the test is connected in service. However, where the circuit contains a mid-point permanently connected to earth, U shall be taken to be one-half of this supply voltage.

b) *Test on single piece of apparatus*

1) *Test on convertor assembly* — All dc and ac terminals of convertor assembly shall be joined together and diodes short circuited to ensure that high voltage is not applied across the diodes. The rms value of test voltage shall be:

$$2\,000 \text{ V or } \frac{2\,U_m}{\sqrt{2}} + 1\,000$$

whichever is larger, U_m is the highest crest voltage to be expected between any pair of terminals. If the voltage to the ground is higher than between two terminals (for example, with series connection of convertor equipment) than the higher voltage is to be applied. If the quotient $\frac{U_m}{\sqrt{2}}$ does not exceed 90 volts, the test voltage may be reduced to 1 000 V. If stacks are to be used in electrically exposed conditions, or where considerable switching overvoltages are to be expected, the test voltage may be increased by mutual agreement between the user and the manufacturer.

2) *Dielectric test on reactor and other equipment connected to traction circuit* — For reactors with single insulation the test shall be conducted at a voltage of 2·25 U + 1 000 V.

U being the rated voltage of the circuit to which reactor is to be connected.

3) *Dielectric test on convertor auxiliary machines* — The test shall be carried out at a voltage 2·25 U + 2 000 V, U being the highest voltage (ac or dc) that can be applied to a machine or machine part through the transformer or transformer and convertor when the primary winding of the transformer is supplied at the system voltage of the contact system.

4) *Dielectric test on convertor control and auxiliary circuits*

   i) The voltage shall be applied between main circuits and earth, and between main circuits and control circuits when the apparatus includes windings connected in these circuits and mounted on magnetic circuits which are not permanently earthed*. The test voltage shall be 2·5 U + 2 000 V, U being the rated supply voltage of the circuit.

   ii) Where certain items have double insulation, the dielectric test shall be carried out:

   — between circuit and frame insulated from earth, at a voltage of 2 U + 1 000 V;

   — between insulated frame and earth, at a voltage of 2·5 U + 2 000 V.

   NOTE — Where the main insulation is provided between circuit and frame insulated from earth, the above test voltages shall be reversed.

   iii) Where apparatus is in circuits with rated voltage below 300 V dc or 100 V ac dielectric tests of apparatus and component parts shall be made to earth at a voltage of 1 500 V rms.

---

*However, in certain special cases, after specific agreement between the user and the manufacturer, a test voltage higher than that given by the formula 2·5 U + 2 000 V may be used.

However, for apparatus in circuits of rated voltage less than 30 V, the test shall be carried out at 750 V.

c) *Test on apparatus groups* — When it is necessary to carry out a dielectric test on a group of apparatus, this test shall be made with a voltage equal to 0·85 times the test voltage of the apparatus taken singly.

d) *Tests on equipment mounted on the vehicle* — Before delivery of the stock, each mounted equipment shall be subjected to a dielectric test to earth. Rotating machines and, unless otherwise specified, control apparatus inserted at points in the power circuit or an auxiliary circuit normally subjected in service to a voltage of less than 500 V to earth, shall be disconnected from the circuits to which they belong.

The test shall be carried out at an rms voltage equal to 0·85 times the test voltage defind in **10.2.9.2** (b) (4) for the apparatus in the circuit concerned.

Control apparatus in circuits of rated voltages above 300 V, which, in accordance with the arrangements mentioned above, had previously been disconnected as belonging to a part of these circuits not subjected to a voltage above 500 V, shall be tested individually at a voltage of 2 500 V. After the test insulation resistance shall be verified.

10.2.10 *Tests on Accessories for Convertor Assemblies* — All accessories including blower motor set, resistors, capacitors, surge suppressors and main fuses (where provided) shall comply with the relevant Indian Standards. Type and routine tests on accessories shall be agreed between the purchaser and the manufacturer.

10.2.11 *Tests on Indicating and Functional Units of Convertor Assembly* — All indicating devices and functional units provided on convertor assembly including cell check device, indicating fuses, air flow relay, blower set protections, functional switches, etc, shall comply with the relevant Indian Standards wherever applicable. Type and routine tests to be carried out shall be agreed between the purchaser and the manufacturer.

10.2.12 *Power Loss Measurements* — Losses in the convertors assembly may be determined either by calculations based on measurements or by direct measurements.

The power losses of the convertor shall be measured during the light-load test and a load loss test. The total losses of the convertor is the sum of the no-load losses and load losses calculated from these tests.

10.2.12.1 *Light-load power loss measurements* — The test shall be carried out at a current not lower than is necessary to avoid the light-load voltage rise of the convertor. The input ac power to the convertor shall be measured, including all auxiliary equipment, the losses of which are to be included when calculating the efficiency and whose losses are not significantly dependent upon the load of the convertor. The output power shall be measured by a wattmeter.

The light-load power losses are equal to the input ac power minus the output power as measured.

10.2.12.2 *No load power loss measurements* — The short-circuit connection shall preferably include sufficient inductance so that the harmonics in the direct current are approximately the same as are expected at those load conditions for which the efficiency is to be determined. The test shall generally be conducted according to Appendix H.

If agreed to between the purchaser and the manufacturer, the tests may be conducted with the dc terminals of the convertor assembly short-circuited. During the test, the auxiliary equipment shall be supplied separately with rated voltage and their losses are not included in the short-circuit losses.

The power losses of the convertor at short circuit are equal to the power supplied from the ac supply at the short-circuit test, corrected for core losses in convertor transformer, if existing, and the power losses in the short-circuit connections on the dc side, as determined from measurements of direct current and direct voltage, mean values.

NOTE — The tests may be conducted after forward current sharing test (*see* **10.2.5**).

10.2.13 *Check of Diode Characteristics* — After the completion of the type tests, about 10 percent of the diodes taken from places which are considered to be under most severe thermal conditions in the convertor assembly shall be selected in order to check that the reverse voltage and current and the forward voltage drop still lie within the limits stated by the manufacturer.

10.2.14 *Tests After Installation on Vehicle* — The routine tests to be carried out on completed vehicles comprise of the following checks and tests:

a) Check on correct assembly of convertor components and electrical circuitry;

b) Check on the correct operation of auxiliary machines, indicating devices, functional units and other accessories; and

c) Insulation tests on the various circuits in accordance with the requirements of the relevant Indian Standards.

10.2.15 *Simulated Traction Motor Flashover Test*

10.2.15.1 The convertor equipment, with its protective devices and when operating on the tap which gives the maximum short-circuit current, shall be capable of withstanding without damage and at maximum supply voltage the currents produced by a short circuit in a traction motor circuit with the smoothing reactor, if any, remaining inserted in the fault circuit. The traction motor field may be included or omitted from the circuit as determined by the vehicle power circuit especially by the position of the earthing point, etc.

10.2.15.2 For this test, the vehicle shall be located as close as practicable to a feeder station in order to obtain a fault level at or near the specified value. The vehicle shall be supplied from the contact system at a voltage equal to 110 percent of system voltage, unless otherwise agreed to between the purchaser and the manufacturer. The transformer tap changer shall be in the position giving the maximum value of short-circuit current.

10.2.15.3 In case these limiting values are appreciably higher than those obtainable under normal operating conditions, the level of short-circuit current and its duration shall be mutually agreed between the purchaser and the manufacturer.

10.2.15.4 In order to ensure that this requirement is complied with, the test shall be performed on one complete vehicle of the design concerned.

10.2.15.5 All traction motors shall be disconnected from the power circuit and a suitable loading resistance R_L connected in its place through a contactor L_1. The value of the resistance shall be such that the convertor may be raised in a reasonable period to a temperature equivalent to the one produced by continuous rated current of traction motors. Another short-circuiting contactor L_2 shall be connected in parallel with the loading resistance.

A test circuit is given in Fig. 18.

10.2.15.6 The convertor under test with all its protective equipment in circuit, shall be raised to the normal operating temperatures by means of loading resistance R_L. This may even be achieved at low voltage by keeping the value of R_L low. With the convertor under hot condition, the short-circuiting contactor L_2 shall be closed under the limiting values of transformer tap and line voltage. The resulting fault current shall be detected and cleared by the protective and fault clearing equipment in the total time specified for the equipment.

10.2.15.7 The test shall be made once and oscillographic records shall be made as agreed between the purchaser and the manufacturer. These shall generally comprise of line voltage, ac input voltage to convertor and short-circuit current progression with time.

10.2.15.8 After the test the convertor shall be checked at the ambient temperature to verify that no failure of any component part has occurred.

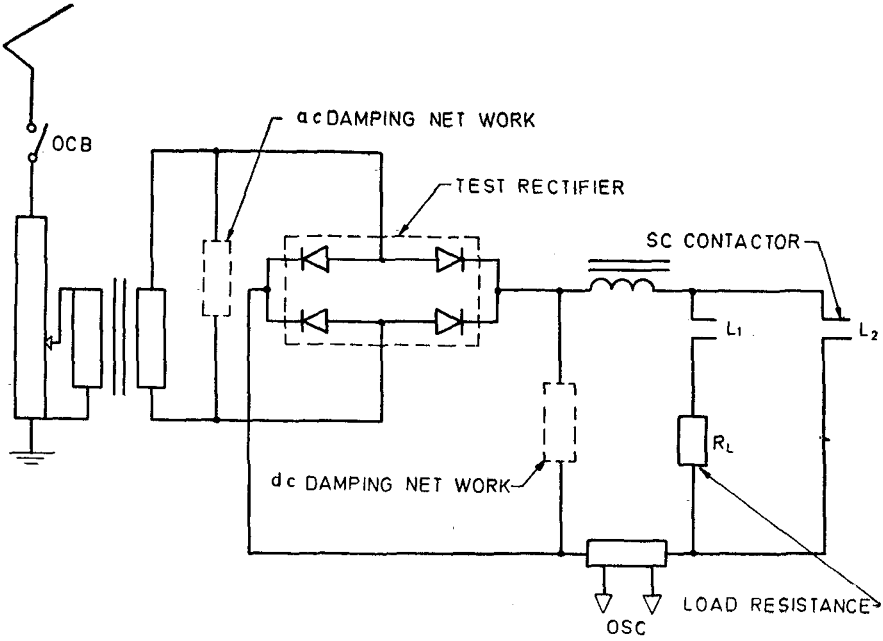


Fig. 18 Circuit for Simulated Traction Motor Flash Over Test

10.2.16 *AC Circuit-Breaker Switching Test*

10.2.16.1 The test shall be conducted on convertor equipment, with its protective devices in circuit, installed on the vehicle. The vehicle shall be supplied from the contact system at a voltage 110 percent of the system voltage, unless otherwise agreed to between the purchaser and the manufacturer.

10.2.16.2 With the power circuits of the vehicle open-circuited and the auxiliary load equal to the minimum value which may occur in service, the main ac circuit-breaker on the vehicle shall be closed and opened six times in order to check the effect on the diodes of surges caused by the interruption of inductive circuits.

10.2.16.3 After the test, the convertor shall be checked at the ambient temperature to verify that no failure of any component part has occurred.

NOTE 1 — If diode failure occurs during any of the tests in **10.2.15** and **10.2.16** the manufacturer shall replace the failed diodes at his own expense, and the test concerned shall be repeated twice. If nothing untoward occurs in the course of these repeated tests, the type tests shall be considered satisfactory. If, however, a further failure occurs the manufacturer shall meet the reasonable requirements of the purchaser for correcting the fault concerned.

NOTE 2 — If during the above tests, the failure of convertor occurs due to maloperation of clearing equipment or any other associated vehicle equipment, on liability shall rest with the convertor manufacturer.

11. TOLERANCES

11.1 If guarantees are given, the tolerance on the guaranteed value of losses in the convertor assembly shall be + 10 percent.

APPENDIX A

(*Clause* 0.5)

SYMBOLS USED IN ELECTRICAL CHARACTERISTICS OF DIODES AND DIODE STACKS

i_F	Forward current (instantaneous value)
i_R	Reverse current (instantaneous value)
I_{FM}	Maximum forward current
I_{RM}	Peak reverse current
I_{FAV}	Mean forward current (full cycle average)
I_{FAVM}	Maximum of I_{FAV}
I_N	Nominal value of I_{FAV}
$I_{F(OV)}$	Overload forward current
$I_{F(OV)M}$	Maximum of $I_{F(OV)}$
I_{FRM}	Repetitive peak forward current
I_{FSM}	Surge forward current
I_{FRMS}	RMS forward current
I_{FRMSM}	Limiting value of I_{FRMS}
I_{Fint}	Forward current for intermittant operation
P	Power dissipation
P_F	Forward power loss
P_{tot}	Total power dissipation
P_R	Reverse power loss

Q_{RR}	Reverse recovery charge
r_F	Forward slope resistance
R_{th} JC	Thermal resistance, junction to case
R_{th} CA	Thermal resistance, case to Ambient
R_{th} JA	Thermal resistance, junction to Ambient
T_A	Ambient temperature
T_c	Case temperature
T_{vj}	Virtual junction temperature
t_{RR}	Reverse recovery time
t_{Stg}	Storage time
u_F	Forward voltage (instantaneous value)
u_R	Reverse voltage (instantaneous value)
U_{TO}	Threshold voltage
U_{BR}	Reverse breakdown voltage
U_{RRM}	Repetitive peak reverse voltage
U_{RWM}	Maximum crest working reverse voltage
U_{RSM}	Maximum non-repetitive, that is, transient peak reverse voltage
U_{NRMS}	Recommended RMS supply voltage
U_{RN}	Nominal that is recommended crest working reverse voltage
$Z_{(th)t}$	Transient thermal impedance.

APPENDIX B

(*Clause* 5.2.1)

VALUES OF NOMINAL SUPPLY VOLTAGES OF TRACTION SYSTEMS AND LIMITS OF VARIATION OF LINE VOLTAGE

	VOLTAGES			NOMINAL FREQUENCY OF ac NETWORKS
	Minimum	Nominal	Maximum	
Single-phase networks	4 750 volts	6 250 volts*	6 900 volts	50 Hz
	—	11 000 ,, †	12 100 ,,	$16\frac{2}{3}$Hz—25Hz
	12 000 ,,	15 000 ,,	16 500 ,,	$16\frac{2}{3}$ Hz
	19 000 ,,	25 000 ,,	27 500 ,,	50 Hz

---

*It is recommended that the voltage of 6 250 volts should be used only when local conditions make it impossible for the voltage of 25 000 volts to be adopted.

†It is recommended that for $16\frac{2}{3}$ Hz single-phase traction installations to be erected in future, the voltage of 11 000 volts should be replaced by 15 000 volts.

APPENDIX C

(*Clause* 5.2.2)

LIMITS OF VARIATION OF AUXILIARY SUPPLY VOLTAGE

C-1. With the exception of the special cases forming the subject of **C-2** to **C-6**, electrical, electromagnetic or electro-pneumatic equipment shall operate satisfactorily at any value of supply voltage between 0·7 U and 1·25 U, U being the rated supply voltage.

C-2. When the supply voltage is directly dependent on that of an ac contact system, the upper limit mentioned in **C-1** is to be altered to 1·1 U.

C-3. In the case of equipment supplied either by an auxiliary generator provided with a voltage regulator or by a generator, the voltage of which is completely independent of the contact system, the limits given in **C-1** are to be altered to 0·8 U and 1·1 U respectively.

C-4. When the supply voltage is provided by an accumulator battery having special arrangements for the correction of voltage variation (for example, different cell groupings on charge and on discharge), a relaxation of the limits specified in **C-1** may be allowed by agreement between the purchaser and the manufacturer.

C-5. For equipment supplied from a stabilized source, the limits of supply voltage variation shall be decided by agreement between the purchaser and the manufacturer.

C-6. In special cases involving large voltage drops, for example, where the vehicle comprises equipment or devices taking high currents, such as electromagnetic brakes, the lower limits given above may be reduced to a value fixed by agreement between the purchaser and the manufacturer.

APPENDIX D

(*Clause* 6.1.3)

GENERAL RECOMMENDATIONS FOR MECHANICAL CONSTRUCTION

D-1. The convertor cubicle shall preferably be of metal sheet construction with a strong framework to withstand normal vibrations and shocks of vehicle in service. The minimum thickness of sheet steel enclosures shall preferably be according to Table 4.

TABLE 4 MINIMUM THICKNESS OF SHEET STEEL ENCLOSURES

(*Clause* D-1)

Maximum Panel Width (1)	Minimum Thickness of Steel Sheet (2)
mm	mm
125	0·63
250	0·90
500	1·60
750	2·00
1 500	2·50
2 000	3·15

Note — The width is the smaller of the two dimensions of rectangular panel.

D-2. Easily removable covers or door with suitable grips shall be provided for quick and easy accessibility of equipment inside cubicle. The covers shall preferably be in two parts, one for diode panel and the other for blower motor set.

D-3. Suitable ventilating openings or louvers shall be provided for the enclosed panels wherever necessary. The size and shape of openings shall be suitably designed to avoid accidental exposure of live parts.

D-4. The layout of equipment in the cubicle shall provide for easy accessibility of equipment for maintenance/replacement preferably without having to remove associated components.

D-5. The convertor blower motor set shall preferably be mounted as an independent unit inside the main cubicle frame, suitably connected to the main convertor cooling duct. It shall be possible to remove blower set for maintenance purposes without having to lift the convertor cubicle or other equipment inside the vehicle. Adequate resilience shall be provided between the blower and convertor duct to reduce the vibrations and allow for manufacturing tolerances of the blower and convertor assembly.

D-6. The air flow in forced ventilated units shall be such as to draw comparatively dust free air and provide a uniform flow over all cooling fans. On vertically mounted cubicles blower shall preferably be placed at the bottom of cubicle, providing an air flow from top to bottom. Sufficient free space shall be provided at the cubicle air inlet and outlet to allow for unrestricted air flow.

D-7. The floor mounted convertor cubicle shall be provided with suitable base frame so as to transfer its weight on the main members of vehicle underframe. In case of cubicles with high centre of gravity, provision shall be made to provide suitable stays at the top/sides of the cubicles when mounted on the vehicle, to make the unit sufficiently stable to withstand vibrations/shocks under service conditions.

D-8. Wherever applicable, all indicating devices provided on the cubicle shall be clearly visible from the vehicle corridor and the functional switches shall be easily accessible for operation.

D-9. In case of underslung convertor equipment mounted from the vehicle underframe, adequate precaution shall be taken to prevent any accidental loosening or falling out of the convertor equipment or any of its ancillary equipment. The equipment shall also be suitably protected against damage due to flying ballast and the design shall be made dust-proof and waterproof with suitable filters.

APPENDIX E

(*Clause* 6.2)

GENERAL RECOMMENDATION FOR ELECTRICAL CONSTRUCTION OF CONVERTOR CUBICLES

E-1. All electrical connections, including those of diodes, its associated components, etc, shall be of high quality using crimped terminals, standard lugs, nuts, bolts and plated spring steel washers to ensure good electrical connection and facilitate maintenance.

E-2. The connections to the ac bus bars inside the cubicle shall be by easy accessible links for isolation of defective convertor.

E-3. All wirings shall be done with high quality multistrand wires/cables and shall be neatly and separately laid for power and auxiliary circuits according to high, medium and low voltages.

E-4. All the wires shall be numbered according to the wiring diagram and terminated at suitable terminal boards so as to facilitate removal/replacement of components without having to open any internal wirings.

E-5. All electrical equipment including insulators, cables, etc, used for fabrication of convertor cubicle shall be with suitable insulation level for traction/auxiliary circuit voltages and shall be able to withstand high temperatures inside the traction vehicle without any deterioration.

E-6. The current density in cable, bus bar etc, shall be kept reasonably low so that the temperature under working conditions does not exceed the normal limits. The recommended limit of current densities are 2·5 A/mm^2 for cables and 4·0 A/mm^2 for bus bars with a maximum temperature of 100°C for the latter.

E-7. Adequate clearance and creepage distances shall be maintained in the cubicle layout for all live parts to avoid internal flashovers. These shall generally conform to **4** of IS : 6619-1972* with suitable extra allowance for pollution of air with oil and dust inside the traction vehicle, wherever necessary. The recommended minimum clearances are given in Table 5. Wherever the minimum specified clearances are not attainable, all live parts shall be suitably insulated/taped to the required insulation level.

TABLE 5 MINIMUM SPACINGS

(Phase to Phase and Phase to Earth)

CIRCUIT VOLTAGE		CONTROL CIRCUIT		POWER CIRCUIT CIRCUIT FAULT CURRENT LEVEL			
AC	DC	Through Air	Along Dry Surface	Less than 10 kA		10 kA and above	
				Through Air	Along Dry Surface	Through Air	Along Dry Surface
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
V	V	mm	mm	mm	mm	mm	mm
51 to 125	51 to 125	3	6	3	6	13	19
126 to 250	126 to 250	5	10	6	10	19	32
251 to 500	251 to 500	5	13	10	13	25	51
501 to 600	501 to 750	6	25	10	25	25	51
601 to 1200	751 to 1500	—	—	—	—	38	64
1201 to 1800	1501 to 2000	—	—	—	—	50	70
1801 to 2500	2001 to 3000	—	—	—	—	64	76

---

*Safety code for semiconductor rectifier equipment.

APPENDIX F

(*Clause* 8.1)

INFORMATION TO BE SUPPLIED BY THE PURCHASER AT THE TIME OF SUPPLY

Sl No.	*Equipment*	*Data and Specification*		
1.	Main Circuit-Breaker:			
	Type/Make	....		
	Tripping characteristics	Instantaneous/Inverse		
	Clearing period	.... ms		
2.	(a) Lightning Spark Gap Across Line Winding:			
	Air spark gap			
	range	.... mm to ...... mm		
	set value	.... mm to .... mm		
	Maximum impulse sparkover voltage	......V(peak) (1·2/50 μs wave)		
	100 percent impulse sparkover voltage	...... V (peak)		
	OR			
	(b) Surge Arrestor Across Line Winding:			
	Type/Make	....		
	Rated voltage	 V		
	Maximum permissible service voltage	 V		
	50 Hz sparkover voltage	....		
	Maximum 1·2/50 μs wave sparkover voltage	....		
3.	Main Transformer:			
	Type/Make			
	Rating	Primary	Secondary	Auxiliary
	kVA	...	...	...
	Voltage	...	...	...
	Current	...	...	...

Sl No.	*Equipment*	*Data and Specification*
	No load magnetising current	
	at nominal line voltage	... A at ... kV
	at maximum line voltage	... A at ... kV
	Percentage impedance voltage	
	at operating tap ...th	... percent at IR ... A
	at maximum tap ...th	... percent at IR ... A
4.	Overload Protection Across Line Winding:	
	Current transformer	
	Type/Make	......
	Current ratio	......
	Rating	......VA
	Overload relay	
	Type/Make	
	Range	
	Set value	
	Fault clearing period	.........ms (operating through main circuit breaker DJ)
5.	Over-Voltage Protection Across Cell Winding:	
	Surge arrestor	
	Type/Make	......
	Rated voltage	......V (rms)
	Max permissible service voltage	......V (rms)
	50 Hz sparkover voltage	......V (rms)
	100 percent sparkover voltage 1·2/50 μs/wave	......V (peak)

NOTE — R-C surge divertor, earthing condenser and dc damping network to form the part of convertor design.

6.	Overload Protection on Cell Winding:	
	Current transformer	
	Type/Make	
	Current ratio	
	Rating	......VA
	Overload relay	
	Type/Make	
	Range	
	Set value	
	Fault clearing period	......ms (operating through circuit breaker DJ)

Sl No.	*Equipment*	*Data and Specification*
7.	Smoothing Reactor:	
	Type/Make	......
	Inductance at rated current	......mH
	Inductance at saturation (for iron core reactors only)	......mH
	Resistance at 75°C	......ohm
8.	Traction Motor:	
	Type/Make	
	Continuous rating	......V......As ......rpm
	One hour rating	......V..... As..... rpm
	Max field strength	......percent FF
	Min field strength	......percent FF
	Resistance at 110°C:	
	Armature	..... ohm
	Main field	..... ohm
	Commutating field	......ohm
9.	Traction Motor Overload Relay:	
	Type/Make	
	Range	
	Set value	
	Fault clearing period	......ms (operating through circuit-breaker DJ)
10.	Traction Motor Over Voltage Relay:	
	Type/Make	
	Range	
	Set value	
11.	Accelerating Relay (applicable for EMUs):	
	Type/Make	
	Range	
	Set value for:	
	High acceleration	
	Low acceleration	
12.	Limits of Supply Voltage:	*Max* *Nominal* *Min* *Emergency*
	Line voltage	....
	Auxiliary voltage	....
	Control voltage	....
13.	Power and Auxiliary Circuit Diagrams of Vehicle	Suitable diagram may be supplied

Sl No.	*Equipment*	*Data and Specification*
14.	General Layout of Equipment Inside Vehicle	Suitable diagram may be supplied
15.	Mounting Details of Convertor Assembly with Limiting Dimensions	,,
16.	Recommended Convertor Cubicle Size	,,
17.	Recommended Location of External Cables and Major Equipment of Convertor Assembly	,,
18.	Convertor Circuit Arrangement	Bridge/Push-pull
19.	No. of Convertor Units per Vehicle	……Parallel/……series
20.	Connected dc Load	Traction motors/Aux motors control circuit etc (Details to be given)
21.	Rated Voltage of Load Circuit	……V (DC)
22.	Traction motor/or Auxiliary Load Rating:	
	Continuous	……V……A
	One hour	……V……A
23.	Traction motor/or auxiliary load protective relays setting, if applicable:	
	Over voltage	……V
	Over current	……A
24.	Convertor Voltage Ratings:	
	Maximum no load voltage of cell winding at 1·1 U_{L}	……V rms at……tap
	Cell winding Surge arrestor:	
	Power frequency spark over voltage	……V rms
	1·2/50 μs impulse spark over voltage	……V (peak)
	Line winding lightning spark gap/ or surge arrestor	
	Maximum impulse sparkover voltage	……V (peak)

Sl No.	*Equipment*	*Data and Specification*
25.	Convertor current ratings:	
	Continuous rated direct current	......A
	Mean accelerating current	......A
	Starting duty cycle	Suitable diagram may be supplied
26.	Expected Short Circuit Current with Smoothing Reactor in Circuit:	
	Under Limiting Conditions at ......kV......tap	......kA* (asymm)
	Under Operating Conditions at ......kV......tap	......kA* (asymm)
27.	Short Circuit Fault Clearing Period	......ms
28.	Maximum Cooling Air Temperature	......60°C
29.	Expected Temperature Rise of Air in the Convertor Assembly	......15°C*
30.	Special Operating Conditions, if any:	
	Duty cycle with one string eliminated	
	Duty cycle with half equipment eliminated	

APPENDIX G

(*Clause* 8.2)

TECHNICAL DATA OF DIODE AND CONVERTOR ASSEMBLY TO BE SUPPLIED BY THE MANUFACTURER

Sl No.	*Specification*	*Data*
1.	DIODE DATA	
1.1	Type and Make:	
	— Diode	
	— Fin	
1.2	Average Forward Current with Air Cooling	
	a) Natural	A
	b) Forced m/s	A
	at ambient temperature of 60°C and with maximum base temperature ... °C	

---

*The values shall be verified by the manufacturer.

Sl No.	*Specification*	*Data*
1.3	Recommended Crest Working Reverse Voltage at Rated Junction Temperature	V (peak)
1.4	Repetitive Peak Inverse Voltage at Rated Junction Temperature	V (peak)
1.5	Non-Repetitive Peak Reverse Voltage at Rated Junction Temperature	V (peak)
1.6	Test Reverse Voltage at Manufacturer's Works at Rated Junction Temperature	V (peak)
1.7	Forward Voltage Drop Characteristics	Curves may be supplied
1.8	Forward Power Loss *Vs* Forward Current Curve	Curves may be supplied
1.9	Forward Current *Vs* Cooling Air Temperature Curve at Specified Cooling ...... m/s	Curves may be supplied
1.10	Maximum Reverse Current at Rated Reverse Voltage at Rated Junction Temperature	mA
1.11	Overload Characteristics	Curves may be supplied
	— Surge limit current with no reverse voltage	
	— Surge forward current with 50 percent reverse voltage	
1.12	Maximum Peak Surge Limit Current at Rated Load Conditions (...... Conduction)	A
	— for 10 ms	A
	— for 100 ms	A
1.13	I^2t value:	
	— for 10 ms	$A^2s \times 10^3$
	— for 100 ms	$A^2s \times 10^3$
1.14	Maximum Rated Junction Temperature	°C

Sl No.	*Specification*	*Data*
1.15	Type of Junction	Alloyed/Diffused, etc
1.16	Thermal Resistance of Diode (Junction to Base)	°C/W
1.17	Thermal Resistance of Heat Sink Type (Base to Cooling Air):	
	a) With forced cooling	°C/W
	b) With natural cooling	°C/W
1.18	Transient Thermal Impedance Curve of Heat Sink and Diode	Curves may be supplied
1.19	Temperature Limit of Diode Base at Rated Current	°C
1.20	Weight of Diode	kg
1.21	Weight of Heat Sink	kg
2.	CONVERTOR ASSEMBLY DATA	
2.1	Number of Convertor Cubicles per Vehicle	
2.2	Series/Parallel Arrangement of Convertor Cubicles on Vehicles	
2.3	Number of Diodes in Series in Each String	
2.4	Number of Strings in Parallel in Each Arm	
2.5	Number of Diodes per Arm	
2.6	Number of Diodes per Cubicle	
2.7	Total Number of Diodes per Vehicle	
2.8	Continuous Direct Current Rating of Convertor at Rated Voltage and Specified Air Temperature of ...... °C	
	a) With all strings/bridges in circuit	
	b) With one string/bridge eliminated	

Sl No.	*Specification*	*Data*
2.9	Detailed Characteristics of Protective Devices Against Overloads	
2.10	Technical Data of Devices Used for Protection Against Surge Voltages: — Main surge arrestor — Main R-C net work and earthing condenser — Diode hole storage and potential divider circuit — do damping network	
2.11	Details of Device for Checking Defective Cells/Fuses in the Convertor Assembly	
2.12	Diagram Showing Cell Connections of Convertor Assembly	
2.13	Blower Motor Type, Data and Characteristics at Operating Voltage $0{\cdot}75U$ to $1{\cdot}1U$	
2.14	Type, Data and Characteristics of Protective Relay used for Protection/Indication of Blower Failure	
2.15	Dimensions of Each Cubicle	
2.16	Weight of Complete Equipment with its Auxiliaries	

APPENDIX H

(*Clause* 10.2.12.2)

LOSS MEASUREMENT BY SHORT-CIRCUIT METHOD

H-1. The dc terminals of the stack or assembly are short-circuited, and its ac terminals are supplied through sufficient reactance to cause the input current to be practically sinusoidal, at a voltage sufficient to cause the desired value of the current to flow and at rated frequency. The input power is measured at the ac terminal of the stack or assembly. The wattmeters used shall be suitable for the low voltage and care shall be taken to ensure that the effects of stray magnetic fields are rendered negligible.

The short-circuit tests are performed in quick succession at rated direct current I_{dN} and at $k.I_{dN}$, where

$$k = \frac{\text{form factor of arm current in real service}}{\text{form factor of arm current at test}} \text{ (neglecting overlap)}$$

A first measurement of losses P_2 is made after reaching constant temperature at $k.I_{dN}$. A second measurement of losses P_1 is made as quickly as possible after reducing the current to I_{dN}.

The losses P corresponding to rated direct current in normal service is calculated by means of the following formula:

$$P = \frac{k+1}{k} P_2 - k.P_1$$

Where appropriate the loss in the dc short-circuiting connections and shunts, if appreciable, is to be measured and deducted from P_1 and P_2.

INDIAN STANDARDS

ON

POWER CONVERTORS

IS:

1885 (Part XXVII)-1969	Electrotechnical vocabulary: Part XXVII Static power convertors
2511-1963	Polycrystalline semiconductor rectifier stacks
3136-1965	Polycrystalline semiconductor rectifier equipment
3895-1966	Monocrystalline semiconductor rectifier cells and stacks
4540-1968	Monocrystalline semiconductor rectifier assemblies and equipme
6619-1972	Safety code for semiconductor rectifier equipment
7204 (Part I)-1974	Stabilized power supplies dc output: Part I Terms and

---

INDIAN STANDARDS INSTITUTION
Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002
Telephone : 27 01 31 (20 lines) **Telegrams : Man**

Regional Offices:
Western : Novelty Chambers, Grant Road BOMBAY 400007
Eastern : 5 Chowringhee Approach CALCUTTA 700072
Southern : C. I. T. Campus, Adyar MADRAS 600020

Branch Offices:
'Pushpak', Nurmohamed Shaikh Marg, Khanpur AHMADABAD 380001
'F' Block, Unity Bldg, Narasimharaja Square BANGALORE 560002
Kothi No. 90, Sector 18A CHANDIGARH 160018